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University of Cape Town

THE LATE QUATERNARY HISTORY OF SOUTHERN HEMISPHERE MEDITERRANEAN CLIMATE REGIONS IN THE WESTERN CAPE, SOUTH AFRICA, AND SOUTHWESTERN AUSTRALIA

BY

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Abstract

This thesis presents Late Quaternary palaeoenvironmental information from the mediterranean-climate regions found in the Western Cape, South Africa, and southwestern Australia. The study is focused on four study sites, two in the Western Cape, namely the Bruno section and Lake Michelle and two in southwestern Australia, namely Wambellup Swamp and Devil's Pool. These sites were chosen as they are well situated to investigate the complex interaction between Late Quaternary climate change, the influence of fluctuating sea levels and the impact of human interaction with the environments in question and provide a regional picture of these interactions. In order to facilitate this investigation, sediments at the four study sites were sampled by a number of means, including the use of a vibra corer and a D-section Russian corer. These samples were then subjected to palynological investigation, analysis of organic matter content and, for a number of samples, δ 13C analysis. Chronological control for the sampled sediments was provided through radiocarbon dating techniques.

Evidence from the base of the Bruno section, dated at c12 200 B.P. suggests wet and dry phases possibly synchronous with the time of the Younger Dryas event, leading to a drier Early Holocene. A wet phase centred around the Mid Holocene gives way to a drier phase in the Late Holocene period. Evidence from Lake Michelle suggests that this site has been heavily impacted by sea level fluctuations, with several marine incursions, the last of which is thought to represent Mid Holocene high sea levels. The picture that emerges from this site is of a generally drier Mid to Late Holocene period. Wambellup Swamp provides evidence for a generally drier Early Holocene, with moister conditions from the Mid Holocene to the present. The Devil's Pool site provides evidence of a wetter period around the Early Holocene, leading to a drying period in the Mid Holocene, possibly associated with the Mid Holocene Optimum. The generally wetter Late Holocene at Devil's Pool is punctuated by a number of short lived dry phases. The regional picture that emerges from the four study sites is of little coherence in the data representing the Early to Mid Holocene, but of a generally drier Mid to Late Holocene in

the Western Cape, and of a generally wetter Mid to Late Holocene in southwestern Australia.

The relative importance of human impact on the environments in the two regions is also investigated in this thesis. Data from the four study sites suggests that evidence for pre-colonial human impact on these environments is very subtle and difficult to detect, with only minor fluctuations visible in the pollen assemblages. The effects of colonial and post –colonial human impact on the environments is on the other hand far more obvious with clear evidence visible in the pollen spectra. It is evident that some of the most dramatic shifts in vegetation communities in recent times can be attributed directly to human impact.

The significance of this study is that it provides important data concerning the Late Quaternary history of two extremely biodiverse and species rich regions over a time period characterised by changes in climate, fluctuations in sea levels and unprecedented human influence. Analysis of all these factors brings us closer to understanding their role in the maintenance of the extreme biodiversity found in these regions, an understanding which is crucial to the future management of these areas of global significance.

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Table of contents:

Chapter 1: Introduction 1

1.1 The significance of Quaternary environmental change 3

1.2 Methods of investigating Quaternary environmental change 4

1.3 Principles of pollen analysis 7

1.4 Problems associated with pollen analysis 9

1.5 A brief introduction to the Quaternary in the Western Cape 12

1.6 A brief introduction to the Quaternary in southwestern Australia 13

1.7 General research aims 15

1.8 Specific research objectives 17

1.9 Thesis structure 18

Chapter 2: Literature Review, The Late Quaternary in Southwestern Australia and the Western Cape, South Africa 21

2.1 The Western Cape, South Africa 21

2.1.1 Last Glacial Maximum 23

2.1.2 Early Holocene 25

2.1.3 Mid-Holocene 27

2.1.4 Late Holocene 29

2.1.5 Human Influence 31

2.2 Southwestern Australia 37

2.2.1 Last Glacial Maximum 38

2.2.2 Early Holocene 39

2.2.3 Mid Holocene 40

2.2.4 Late Holocene 43

2.2.5 Human Impact 44

2.3 Global events in the Late Quaternary 49

Chapter 3: Site Descriptions

Regional Setting 52

3.1 Western Cape 52

3.1.1 Geology 52

3.1.2 Regional Climate 54

3.1.3 Vegetation 60

3.1.4 Fire 65

3.2 Southwestern Australia 66

3.2.1 Geology 66

3.2.2 Regional Climate 70

3.2.3 Vegetation 75

3.2.4 Fire 80

3.3 Local Setting: Western Cape 82

3.3.1 Bruno section 83

3.3.1.1 Description of site 83

3.3.1.2 Local Geology 85

3.3.1.3 Local Climate 85

3.3.1.4 Local Vegetation 86

3.3.1.5 Degree of Disturbance 86

3.3.2. Lake Michelle, Noordhoek 88

3.3.2.1 Description of site 88

3.3.2.2 Local Geology 90

3.3.2.3 Local Climate 91

3.3.2.4 Local Vegetation 91

3.3.2.5 Degree of Disturbance 92

3.4 Local Setting: Southwestern Australia 93

3.4.1 Wambellup Swamp 94

3.4.1.1 Description of site 94

3.4.1.2 Local geology 96

3.4.1.3 Local Climate 96

2.4.1.4 Local Vegetation 97
3.4.1.5 Degree of Disturbance 98
3.4.2 Devil's Pool 99
3.4.2.1 Description of site 98
3.4.2.2 Local Geology 101
3.4.2.3 Local Climate 101
3.4.2.4 Local vegetation 102
3.4.2.5 Degree of Disturbance 103

Chapter 4: Methodology 104
4.1 Field sampling techniques 104
4.1.1 Bruno section 104
4.1.2 Lake Michelle 106
4.1.3 Wambellup Swamp 108
4.1.4 Devil's Pool 110
4.2 Laboratory Techniques 111
4.2.1 Core descriptions 111
4.2.2 Core sub-sampling techniques 112
4.2.3 Carbon Dating 113
4.2.4 Pollen extraction techniques 114
4.2.5 Slide mounting techniques 116
4.2.6 Pollen identification and counting techniques 116
4.2.7 Data processing and analysis 117
4.2.8 Graphic representation of data, dates and stratigraphy 118
4.2.9 Total Organic Content through Loss on Ignition (LOI) 119
4.2.10 δ C13 Carbon Isotope Analysis 120

Chapter 5: Results 121
Western Cape, South Africa 121
5.1 Bruno Section 121

5.1.1 Description of section 121
5.1.2 Total Organic Carbon Content 124
5.1.3 δ13C for Bruno Section, Units 5 and 8 126
5.1.4 Pollen Diagram for Bruno Section, Units 8 and 9 126
5.1.5 Pollen Diagram for Bruno Section, Unit 5 131
5.2 Lake Michelle, Noordhoek 135
5.2.1 Description of core 135
5.2.2 Total Organic Carbon Content 136
5.2.3 Pollen Diagram for Lake Michelle, Noordhoek 137
Southwestern Australia 143
5.3 Wambellup Swamp 143
5.3.1 Description of core 143
5.3.2 Total Organic Carbon Content 143
5.3.3 Pollen Diagram for Wambellup Swamp 145
5.4 Devil's Pool 149
5.4.1 Description of core 149
5.4.2 Total Organic Carbon Content 150
5.4.3 δ C13 values 152
5.4.4 Pollen Diagram for Devil's Pool 153

Chapter 6: Discussion 160
6.1 Western Cape, South Africa 160
6.1.1 Bruno section 160
6.1.1.1 Units 8 and 9 160
6.1.1.2 Unit 5 163
6.1.2 Lake Michelle, Noordhoek 166
6.2 Southwestern Australia 172
6.2.1 Wambellup Swamp 172
6.2.2 Devil's Pool 177
6.3 Comparison of Total Organic carbon content 183
6.4 Synthesis of climate data 185

6.5 The role of human impact in the environment 194
6.5.1 The Western Cape 195
6.5.2 Southwestern Australia 198
6.6 Chapter Conclusions 203

Chapter 7: Conclusions 204
7.1 Environmental conditions in southwestern Australia and the Western Cape 206
7.2 Human impact in southwestern Australia and the Western Cape, South Africa 208
7.3 Biodiversity in southwestern Australia and the Western Cape, South Africa 210
7.4 Recommendations 212

References: 215

Appendices 242
Raw pollen counts and other data for study sites

List of Figures

Fig 2.1 Palaeoenvironmental study sites in the Southern and Western Cape (from Chase and Meadows, 2007) 26

Fig 2.2 Evidence of Human impact at Driehoek, with decreasing numbers of *Widdringtonia cederbergensis* further reduced by human impact. Sugden (1989) 32

Fig 2.3 Evidence of prehistoric and colonial impacts on the environment at Klaarfontain Springs Meadows and Baxter (2001) 33

Fig 2.4 Evidence of Colonial human impact at Verlorenvlei. Baxter and Meadows (1994) 35

Fig 2.5 Map illustrating south west Australian Winter Rainfall zone and Palaeoenvironmental study sites (after Dodson, 2001). 41

Fig 2.6 Pollen diagram from Loch Mc Ness illustrating possible human impacts. Newsome and Pickett (1992) 46

Fig 2.7 Pollen diagram from Byenup Lagoon, indicating *Pinus* in the pollen assemblage. Dodson and Lu (2000) 48

Fig 2.8 Younger Dryas event observed in GISP2 Ice core data. Alley(2000) 50

Fig 2.9 Evidence for 8200 B.P event. von Grafenstein,(1998) 51

Fig 3.1 Geology of the Western Cape (South African Council for Geoscience) 53

Fig 3.2 Annual rainfall for Southern Africa (From Chase, 2006) 57

Fig 3.3 Mean temperature maximum for the Western Cape. (Western Cape Department of Agriculture, based on Schultze, (1997) 58

Fig 3.4 Mean temperature minima for January and July for South Africa (Schulze, 1996) 59

Fig 3.5 Vegetation distribution in the Western Cape (Acocks, Veld types of South Africa, 1988) 60

Fig.3.6. Underlying Geology of Western Australia. Courtesy of the Western Australian Geological Survey. 68

Fig 3.7 Detailed Geology of Western Australia. Courtesy of Western Australian Geological Survey. 69

Fig 3.8 Average maximum annual temperatures for Western Australia. (Australian Bureau of Meteorology) 71

Fig.3.9 Average minimum annual temperatures for Western Australia. (Australian Bureau of Meteorology) 72

Fig 3.10 Annual average rainfall distribution for Western Australia (Australian Bureau of Meteorology) 73

Fig 3.11 Vegetation distribution patterns in south western Australia (C.A.L.M) 77

Fig 3.12 Location of study sites in the Western Cape, South Africa 82

Fig 3.13 Satellite image of Bruno Section and surrounds 83

Fig 3.14 Satellite image of Lake Michelle and surrounds 88

Fig 3.15 Location of Study sites in Southwestern Australia 93

Fig 3.16 Satellite image of Wambellup Swamp and surrounds 94

Fig 3.17 Satellite image of Devil's Pool and surrounds. 99

Fig 4.1 The blue prints for a vibracorer (from Baxter, 1999) 108

Fig 4.2 Diagram of Russian D-section corer 109

Fig 5.1 Description of Bruno Section illustrating position of Units 5, 8 and 9 123

Fig 5.2 Total Organic Carbon content for Bruno sectio , Units 8 and 9 124
Fig.5.3 Total Organic Carbon content for Bruno section, Unit 5. 125
Fig 5.4 Pollen diagram for Bruno section units 8 and 9. 127
Fig 5.5 Pollen diagram for Bruno section unit 5 132
Fig 5.6 Organic matter content for Lake Michelle, Noordhoek 137
Fig 5.7 Pollen diagram for Lake Michelle, Noordhoek 139
Fig 5.8 Organic matter content for Wambellup Swamp 144
Fig 5.9 Pollen diagram for Wambellup Swamp 146
Fig 5.10 Organic matter content for Devil's Pool. 151
Fig 5.11 δ C13 values for Devil's Pool 152
Fig 5.12 Pollen diagram for Devil's Pool 154
Fig 6.1 Summary of Climate data from the Western Cape and south western Australia 187
Fig 6.4 Holocene sea levels in the Western Cape 189

List of plates

Plate 3.1 View of Sand River valley containing Bruno section 84
Plate 3.2 Coring the edge of Lake Michelle wetland. 89
Plate 3.3 Wambellup Swamp 95
Plate 3.4 Devil's Pool from northern ridge. 100
Plate 4.1 Sampling units 8 and 9 of the Bruno section by hand 105
Plate 4.2 A vibracorer in use 106
Plate 4.3 Retrieval of a core using a tripod and pulley system at Lake Michelle, Noordhoek 107
Plate 4.4 Sampling sediments at Devils's Pool with a Russian corer. 111

List of tables

Table 3.1 Climate data for selected sites in the Western and Southern Cape. 56
Table 3.2 Climate data for selected sites in south western Australia 74
Table 5.1 Description of Sediments from the Bruno section 122
Table 5.2 δ 13C values for Bruno section, units 5 and 8 126
Table 5.3 Description of sediments from Lake Michelle 136
Table 5.4 Description of sediments from Wambellup Swamp 143
Table 5.5 Description of sediments from Devil's Pool 150

Chapter 1: Introduction

The Southern Hemisphere mediterranean-type heathlands such as those represented in the Western Cape, South Africa and in southwestern Australia, represent some of the most floristically biodiverse regions in the world (Myers, 2003), second only in species richness to that recorded in selected rainforests. Over 8500 species recorded in the Western Cape (Cowling *et al.*, 1995) and over 8000 species recorded in southwestern Australia (Dodson and Lu, 2000) with a degree of endemism of approximately 70% in the Western Cape and around 79% in southwestern Australia (Beard, 2000). Although large areas of this biodiverse heathland survive in the Western Cape and southwestern Australia, much remains to be learned with regards to their respective longer term and more recent evolutionary histories, and our understanding of the mechanisms creating and maintaining extreme biodiversity in these regions is far from complete. Similarity, at least to family level of the floras found in the Western Cape and south western Australia can be attributed to their common ancestry on the Gondwanan plate, with ancient families, predating the rifting of this plate being found in both regions (Cowling *et al.*, 1997). What remains to be explained is the development and parallel evolution of extreme biodiversity in these regions despite differences in climatic and environmental histories. Although there are a number of differences between the two regions, the parallel development of diversity in these two floral regions has been ascribed to the fact that both areas are dominated by old, stable, deeply weathered and nutrient deficient landscapes, as well as long unglaciated periods and climates influenced by oceanic moderation since the Jurassic (Hopper and Gioia, 2004). Although the initial

development of these floras may prove to be beyond the temporal scale of the deposits under scrutiny in this project, it is possible that significant evolutionary processes in these floras took place within the more recent past that is the Quaternary (Kershaw, 1994; Singh, 1981). It is important to understand the development of a major ecosystem type over a period of time which has been characterised by unprecedented climate change in terms of speed and amplitude of change, and it is also important to understand the environmental responses and community dynamics at a timescale beyond ecological research limited to recent monitoring periods. It is hoped that the data generated will feed directly to the conservation of land presently subjected to various forms of land degradation and conversion, and to fire management practices currently based on limited research and input. This lack of research and understanding, with regards to long term responses, particularly in relation to effects of changing fire timing, intensity and frequency means that there is only a reduced basis on which to predict future consequences of present management practices, especially under the threat of rapid global climate change.

Further research that is needed in this regard should be geared toward improving our understanding of vegetation dynamics over longer time scales, and also at a higher resolution than the records currently provide. This thesis attempts to provide data to help address this need. This research should also attempt to identify the factors leading to spatial and temporal vegetation change, and the relative significance of each of these factors.

1.1 The significance of Quaternary environmental change

The focus of research in this thesis is the Late Quaternary, with primary focus being given to the Holocene, a period of time spanning approximately the last 10 000 years. This time period is of particular interest as it encompasses a period of time characterised by unparalleled human influence as well as rapidly changing global climates. The paucity of continuous proxy data records that extend through the entire Holocene and beyond make comprehensive palaeoenvironmental reconstructions for this time period extremely difficult to produce. According to Roberts (1998) all the world's landscapes and ecosystems are products of natural and cultural processes that have shape them over time to bring them to their present state. It is a key aim of Quaternary science, then, to be able to reconstruct and understand the natural and cultural influences on landscapes over a period of time characterised by unprecedented change, largely due to human influence in the more recent past. Although historical records and written documents are useful tools to analyse the more recent past, the time period being studied predates these written records necessitating the use of alternative proxy data to elucidate information regarding environmental change. Various sub-disciplines of Palaeoecology and archaeology have been developed, enabling a multidisciplinary approach to the study of aspects of the Quaternary, with terms such as Historical Biogeography (Linder *et al.*, 1992), bio-archaeology and geo-archaeology (Roberts, 1998) becoming commonplace within the discipline. Palaeoenvironmental studies have enabled the characteristics of past climates to be determined, as well as establishing the directional, spatial and temporal changes of these climates. Furthermore, the verification of climatic gradient changes has enabled the

validation of Global Climate Models (GCMs) aimed at predicting future climate scenarios.

1.2 Methods of investigating Quaternary environmental change

Key to advances in Quaternary research has been advances in dating techniques (Stokes *et al.*, 2003; Thomas and Shaw, 2002). Although the research presented in this study relies on the radiometric technique of radiocarbon dating, advances in other techniques, in particular luminescence dating techniques have proven invaluable when working with organic deprived sediments of arid and semi-arid regions (Stokes *et al.*, 2003; Stokes *et al.*, 1997). The accuracy and precision of conventional radiometric dating techniques has also improved, with smaller error margins providing more finely resolved ages determinations with which to place samples in appropriate temporal context.

A number of methods involving a number of different sources of proxy data have been used to investigate Quaternary environmental change in both Australia and South Africa. A selection of proxies that have been utilised are listed below and include the study of dune and lunette dune sequences (Chase and Thomas, 2006; Zheng *et al.*, 2003), isotope studies on speleothems (Repinski *et al.*, 1999), archaeological studies (Avery, 1992; Dortch, 2004; Klein and Cruz-Uribe, 2000; Parkington, 2002), palynological studies (Baxter, 1996; Beard, 1969; Carr *et al.*, 2006; Coetzee and Praglowski, 1988; Dodson and Lu, 2000; Kershaw *et al.*, 1991; Meadows and Baxter, 2001; Newsome and Pickett, 1993; Scott and Woodborne, 2007a) as well as a number of other methods. Palynology has been

chosen as the primary source of proxy data for this research. Although palynological techniques have been widely used in the northern hemisphere, particularly in the temperate conditions, with the majority of palynological techniques being developed and designed for use in regions where abundance of peaty and organic sediments has lead to good pollen preservation, it has been applied in more arid environments (Horowitz, 1992). Despite problem associated with pollen analysis of sediments in arid environments, such as those described in Horowitz, (1992), various researchers have proven the worth of palynological research both in southern Africa, for example (Baxter, 1996; Carr, 2004; Irving, 1998; Meadows and Meadows, 1988; Scott, 1984; Sugden, 1989) and in Australia (Dodson and Macphail, 2004; Kershaw *et al.*, 1991). In Southern Africa in particular, researchers such as Scott have proven the usefulness of interpreting "non traditional" sediments for palaeoecological studies. Such "non traditional" sediments include the study of hyrax middens as sources of proxy data and even hyena coprolites (Carrion *et al.*, 2000; Scott *et al.*, 2004; Scott and Vogel, 2000; Scott and Woodborne, 2007b). Through the hard work of certain researchers, preparation techniques for pollen analysis suited to "ideal" northern hemisphere conditions have been adapted and modified to deal with the relatively lower levels of preservation and higher taxonomic resolution of pollen in arid land sediments (Baxter, 1999), and the research methodology presented in this thesis leans heavily on the groundwork done by these researchers. Although extensive research has been done on pollen records from northern hemisphere sites, the same cannot be said for the Western Cape and southwestern Australia. The danger therefore is one of regional climate gradients and changes over time being inferred from only a small amount of proxy data from very localised sites.

Given the complexity of these regions in the present day with regards to microclimate, relief, rainfall variability and resultant vegetation distribution, this further serves to highlight these problems. The research presented in this thesis will add palaeoecological data to the slowly increasing data pool from which late Quaternary palaeoenvironmental inferences are made.

There are a number of interacting factors determining the spatial distribution of vegetation in the mediterranean – climate regions of the Western Cape, Africa and southwestern Australia. Climate is a key factor in both of these regions (Scott, 1989; Tyson *et al.*, 2001), and although the two regions experience similar seasonal climatic patterns, the complexities of microclimatic changes (some of which are as a result of changes in relief) also play an important role in determining vegetation distribution. A further key factor is geology (Kendrick *et al.*, 1991), with underlying geological features having direct input into soil formation and therefore having an influence on soil nutrient status, a key element in determining plant distribution. Fire in both of these regions is a significant mechanism for determining plant distribution (Cowling, 1992), with many plant taxa in both regions developing fire survival techniques and indeed methods of using fire in reproduction and dispersal. Perhaps the most important factor, particularly in the past few centuries has been the impact and influence of human interaction with the environment (Conacher, 1998). The relative impact of pre colonial settlement in comparison with colonial and post colonial settlement remains a topic of much discussion and debate. All of these factors are discussed further at various places through this thesis.

1.3 Principles of pollen analysis

Palynology provides a powerful tool for Quaternary research, and although there are many pitfalls and potential problems associated in this technique, which will be discussed briefly later in this chapter, it remains in use and continues to be refined. The development and history of pollen analysis is well described in books by Faegri and Iversen (1989), Moore and Webb (1978) and again by Moore, Webb and Collinson (1991), along with guidelines to practical and theoretical aspects of the technique. A simple summary of the principles that govern fossil pollen analysis has been provided by Birks and Gordon (1985):

- Pollen analyses relies on the fact that flowering plants produce large quantities of pollen, and in the same way, mosses, ferns, algae and fungi produce numerous spores. Only a very small portion of theses spores and pollen grains are used for reproductive purposes, while the rest are distributed by wind and water.
- Atmospheric turbulence as well as hydrodynamics of water serves to mix the pollen into an almost uniform, area-defined pollen rain, which ultimately settles on the ground.
- Pollen or at least its hardened outer sporopollenin rich casing is preserved in accumulating, organic rich sediments under certain conditions where oxidation and decay are prevented. Acidic, anaerobic environments such as permanently waterlogged peat bogs, marshes, swamps and wetlands, provide the necessary environments for pollen preservation.

- Taxonomic identification (at least to family level) relies almost entirely on the morphological differences in pollen structure found between pollen grains from different taxonomic groups. Pollen keys and reference pollen collections provide the means by which pollen grains from various taxonomic groups can be identified.
- It is accepted that the pollen preserved in the sediments reflects the composition of the atmospheric pollen rain, which in turn reflects the vegetation that formerly produced it. The fossil pollen therefore provides a direct view of the former local and regional vegetation at a specific point both spatially and temporally.
- Following on from this, it is accepted that if a number of pollen grains of a known age are counted, identified, and placed within their respective taxa, then the pollen assemblage and spectrum is an index of the vegetation either surrounding the site, or regionally adjacent to the site at the time the collected sediments were deposited. Under ideal conditions, pollen preservation may reach extraordinary concentrations, thus enabling small samples of only $1 cm^3$ to be used for the laboratory preparation.
- If pollen is identified, counted and pollen assemblages obtained from several layers within a stratigraphic sequence, their analysis should provide a sequence of progressive vegetation development at that location through the time period represented by the stratigraphic record.

- If a number of pollen assemblages from different locations are analysed, it should be possible to compare vegetation development through space and time.

Once the above principles are understood, and the necessary steps have been taken in order to reconstruct former plant communities on the basis of the composition of entire plant assemblages in time and space, certain inferences can be made. It is understood that changes in the composition of plant communities with regards to species, is indicative of changes in environmental conditions (Birks and Gordon, 1985). It is therefore understood that these community shifts through time, mirror a sequence of environmental change through time (Baxter, 1996).

1.4 Problems associated with pollen analysis

Although the principles listed above have proven fairly conclusive, yet not entirely inflexible, there remain a number of limitations and possible pitfalls associated with fossil pollen analysis, particularly when analysing material from arid environments. Sugden (1989), Baxter (1996), Faegri and Iversen (1989) and Moore *et al.* (1991) all provide a detailed analysis of limitation and potential pitfalls associated with pollen analysis. Issues pertaining to these limitations include:

- Pollen production: different plants have different pollination strategies, and associated with the different strategies are different rates of pollen

production. Certain wind pollinated plants such as grasses produce large amounts of pollen, most of which are not used in reproductive processes, but ultimately end up being distributed in the pollen rain. Other plants, for example, insect pollinated species, produce a far smaller number of pollen grains, as they rely on a much more precise vector for pollen transportation during reproduction. This disparity leads to a large variation in the fossil pollen representation of certain species when compared with others (Sugden, 1989).

- Pollen dispersal: due to the variation in morphology and size of pollen grains, some are dispersed further a field than others. Thus fossil pollen found in an assemblage may be representative of vegetation at various distances from the site where the sedimentary sequence was sampled. This can skew data, particularly where long distance transport of pollen may introduce pollen into an area of low pollen production.
- Pollen preservation: this is particularly an issue in arid climates where the ideal waterlogged organic sediments needed for pollen preservation may not be common or present at all (Horowitz, 1992). Dry aerobic conditions may also damage pollen grains to such an extent that they may be unidentifiable even if they are present in the sedimentary sequence. Long continuous organic sediments are not common in arid regions, and so pollen preservation may be variable, with pollen only being preserved in selected stratigraphic units within the sequence, thus rendering impossible

the aim of providing a continuous account of vegetation and environmental shifts over time.

- Pollen identification: It is often difficult to identify pollen beyond the taxonomic level of family. This may prove to be a problem, when pollen types with very similar morphologies represent families occurring in different environmental conditions. A solution to this problem is to try and identify the pollen type in context of the other pollen taxa found in the sample. A more difficult scenario to resolve is where members of the same family produce indistinguishable pollen, yet have different environmental requirements, i.e. some members of the Poaceae (Sugden, 1989).
- Preparation losses: certain pollen grains have proved more resistant to the pollen preparation technique than others, and as such, there may be a preferential loss of certain pollen grains from the resultant processed sample.
- Chronology and dating: although dating techniques have improved significantly in the recent past, there are still issues relating to the accuracy and applicability of various dating techniques with regards to variations in substrate being dated. A comprehensive number of dates are still needed for each sedimentary sequence if one is to make any statements regarding the temporal scale and sequence of environmental change.

1.5 A brief introduction to the Quaternary in the Western Cape

Evidence for Quaternary climatic conditions prevalent in the Western Cape is available from a number of sources. Much of this data however, remains poorly dated and even contradictory. For example, climatic conditions surrounding the Last Glacial Maximum (LGM) in the region have been described as cooler and more moist than present (Deacon *et al.*, 1983) and also as cooler and drier (Avery, 1983), which would be more in accordance with evidence from summer rainfall regions which tend toward relative glacial aridity (Partridge *et al.*, 1997). As methods for studying these various proxies have improved over time (along with the improvements in dating techniques) more recent studies perhaps give a more accurate account of conditions during the Late Quaternary. A recent synthesis by Chase and Meadows (2007) makes use of a large number of proxy data sets to make statements about climatic conditions during the late Pleistocene and Holocene of the so-called Winter Rainfall Zone (WRZ) of the region. The conclusions that they present include evidence for cooler, more humid conditions in the early Holocene, followed by warmer drier climates in the Mid Holocene. Moister, cooler climates in the Late Holocene have also been suggested (Chase and Meadows, 2007). A vital part of the Western Cape vegetation history over the Holocene is the fire history. Variations in the fire frequency may have had an impact on the biodiversity of the region, affecting the prevalence and distribution of many plant families (Bond *et al.*, 2003). The effect of human influence on this fire history is also of importance, as changes in land use with the arrival of European settlers have been dramatic, with an altered fire regime. Perhaps some of the most obvious threats to biodiversity in the Western Cape have also

been the most recent, with human influence over the few hundred years. Agricultural practices have led to the transformation of large areas of natural vegetation, in particular the Renosterveld (a fynbos element dominated by *Elytropappus rhinocerotis)*, which tend to occur on reasonably fertile soils, preferred for agriculture (Meadows, 2003). These agricultural practices have also altered the natural runoff and water availability within the region. A further problem associated with recent human influence is the introduction of alien species, in particular Australian members of the *Acacia* genus. These introduced species tend to be from comparable climatic regions, and as such they are able to compete favourably with the local vegetation, and in some areas out compete the local vegetation to such an extent that they form dense stands comprising of a single species, thereby destroying any naturally occurring biodiversity.

1.6 A brief introduction to the Quaternary in southwestern Australia

It has been suggested that the mediterranean-type climates such as those found in Australia may have developed within the last 700 000 years, and that full development of sclerophylly as is evidenced today, possibly took place as recently as 150 000 years ago (Bowler, 1982; Kershaw *et al.*, 2000).The fossil record suggests that there was a shift from temperate rainforest species to sclerophyllous heath and open forest species. These species did not, however, become dominant until the Quaternary. Wasson (1986), Kershaw (1995) and Dodson (1994) suggest that cooler, drier conditions during the (LGM), between 24 ka and 18 ka before present resulted in vegetation patterns different to those found during the remainder of the Holocene. These changes in vegetation

patterns seem to be less marked in the southwestern region, of Australia by comparison to the southeastern region with vegetation patterns showing either very little response to climate change, or being reflective of very little climate change (Dodson, 2001). A decrease in the prevalence of *Casuarina* and *Allocasuarina* from the LGM into the Holocene seems to be one of the more obvious vegetation shifts in the western Australian region (Dodson, 2001). Variations in the relative abundance of *Corymbia callophylla* during the Holocene have also been a point of interest. A warmer wetter mid-Holocene has also been suggested (Dodson and Lu, 2000), although once again, vegetation patterns show no clear response to this when the palynological records are studied (Newsome and Pickett, 1993). Although a charcoal record is available for a few sites in Australia (Atahan *et al.*, 2004; Dodson and Lu, 2000), it is not evident that fire has led to any significant vegetation changes or was indeed as a response to change. It would appear that that vegetation shifts over the Holocene in response to climate change and fire have been very small, but warrant further examination from sites with high resolution data spanning the Holocene. Perhaps the most significant vegetation changes in the region have taken place over the last approximately 200 years with the arrival of colonial settlers (Dodson, 2001). Agricultural practices have led to the clearing of large tracts of native vegetation with little regard to preservation (Conacher, 1998). These agricultural practices have also resulted in the additional problems of increasing salinity in many of the low lying coastal plane areas (Bell *et al.*, 1990; Conacher, 1998). The poor nutrient status of the soils naturally occurring in the region have also posed a problem for agriculture with widespread use of fertilizers a common practice. Pollen data indicate a shift away from woody species, and a decrease in biodiversity associated with these

agricultural practices with a corresponding increase in pioneer species, many from the family Asteraceae (Dodson, 2001). The effect of humans on the fire regime of the region is also a source of great debate, with presumed alteration of the natural fire regime dating back thousands of years to the arrival of Aboriginal peoples in the region (Dortch, 2000). The effects of this altered fire regime on vegetation community composition in the region is still an unresolved question. Modern alteration of fire frequency would appear to be much more prevalent, as is the arrival of alien species in the region tied closely to European settlement. Many of these invasive species are from similar climatic regions such as those found in the Western Cape, South Africa. It is evident that the data available for climate change and environmental response over the Holocene for this region are highly generalised, and that further studies are, accordingly, strongly warranted (Dodson, 2001).

1.7 General Research Aims

The general research aims of this investigation are geared toward the generation of important information regarding regions for which there is limited palaeoenvironmental data available, and during a temporal time frame which is of interest in terms of ubiquitous environmental change and human interaction with the environment. With this time fame, and the two regions being studied in mind, the general research aim for this thesis is:

To investigate the environmental history of high diversity heathland and related vegetation groups over the Late Quaternary in southwestern Australia and the Western Cape, South Africa.

By achieving this main research aim, a number of smaller aims will also be addressed, namely:

- To utilise palaeoecological data gained from pollen analyses, combined with contemporary ecological data in investigating an important but relatively poorly understood component of the flora of South Africa and Australia.

- To provide palaeoecological data to address research objectives of understanding environmental change at as high a degree of temporal resolution as is appropriate.

- To attempt to establish the mechanisms responsible for underlying changes in vegetation distribution.

In order to achieve the above research aims, a number of smaller research objectives were identified. These needed to be addressed and fulfilled as logical steps in the research:

1.8 Specific Research Objectives

1. To identify suitable sites for sampling of Quaternary sediments both in southwestern Australia and the Western Cape South Africa. The sites should have sediments suitable for pollen and charcoal analysis, as well as radiocarbon dating and should be in regions representative of a cross section of the environmental gradients present in each region.
2. Establish a chronology for sediments through radiocarbon dating of appropriate samples.
3. To sub-sample the sedimentary sequences at appropriate intervals and extract pollen from these samples for pollen analysis, thereby constructing a fossil pollen assemblage for each sample from each sedimentary sequence.
4. To process the relevant samples for fossil charcoal analysis in order to understand and compare the specific fire regimes experienced at each site.
5. Evaluate and attempt to assign relative importance to the variables of climate change, fire frequency, soil properties and human influence, both indigenous and colonial in the development of these modern heathland communities

1.9 Thesis structure

1.9.1 Introduction

This section serves to introduce the subject material and to provide an introduction to the study areas and concepts that will be dealt with throughout the thesis. This chapter

introduces the research aims and objectives as well as some of the principles on which the research in the thesis is based.

1.9.2 Literature review

This chapter introduces previous research undertaken with regards to the Late Quaternary histories of the Western Cape, South Africa and southwestern Australia. The chapter presents research centered on specific time periods in the Late Quaternary and also presents research around human impact in the two regions during the Late Quaternary. The chapter also presents information on events of interest in the Late Quaternary; events which may have bearing on the results presented later in the thesis.

1.9.3 Site Descriptions

This chapter describes the chosen study sites in terms of geology, climate and surrounding vegetation, both at a global, regional and local level. This information gives insight into the conditions found at each of the study sites at present day. This information places the study sites in context, especially when compared to the historical conditions suggested by the proxy evidence obtained from each of the study locations.

1.9.4 Methodology

This chapter outlines the methods used while undertaking this investigation. The chapter outlines the field techniques involved in sampling the identified study sites as well as the

laboratory techniques associated with sample processing and extraction. The chapter also deals with data handling techniques and the methods of data presentation used.

1.9.5 Results

This chapter presents the results generated by the sample processing and data handling techniques described in the previous chapter. The data is presented in the appropriate manner pertaining to each type of data set. The focus of this chapter is a number of pollen diagrams produced for various study sites in the Western Cape, South Africa and southwestern Australia.

1.9.6 Discussion

The discussion chapter serves to describe and interpret the raw data presented in the previous chapter and place it against a background of research undertaken by other researchers. This places the data in the context of accepted trends and conclusions, but also serves to either refute or challenge these accepted trends and conclusions derived from previous research. The discussion also further serves to address the research aims.

1.9.7 Conclusion

This purpose of this chapter is to present the conclusions reached from an assimilation of the data in the discussion chapter and to align them to the research aims. The chapter also confirms whether the research objectives have been addressed and furthermore makes

recommendations on the direction and nature of future research in the subject area dealt with in the thesis.

Chapter 2: Literature Review: the Late Quaternary in the Western Cape, South Africa, and southwestern Australia

2.1 The Western Cape, South Africa

Various syntheses have been compiled with regards to the Late Quaternary history of the Western Cape (for example, Chase and Meadows, 2007; Deacon *et al.*, 1983). These papers draw on research, coverage of which is spatially uneven, often poorly dated and also based on data obtained through different methods involving various proxies, including fossil pollen, faunal macro and microfossils, archaeological research and a number of other techniques. Although no single one of these papers can be viewed as the definitive view of the Late Quaternary history of the Western Cape, there are a number of papers requiring special attention as they provide vital information in the quest to reconstruct a picture of conditions during a period of history vital to our understanding of an extremely biodiverse and unique floral kingdom. Special focus is applied to a number of papers, particularly those which are syntheses drawing from a range of proxies, and in particular the most recent syntheses which are the culmination of previous research and more advanced methods and techniques. There are no continuous records spanning the time frame from the LGM to the present, so the data have been arranged within categories describing shorter time periods within this larger time frame. This enables the comparison of data pertaining to each of these shorter time frames, as well as a comparison of the conditions implied by this data. The data has been arranged into four time periods spanning the LGM to the present. The evidence presented within this thesis

is temporally fragmented, with only one site providing data dating back beyond the LGM. The LGM is the period of time at which global ice volumes were at a maximum, and thought to be the strongest expression of glacial conditions. This time period is conservatively placed between 24,000 and 18,000 cal yr B.P. (Clark and Mix, 2002). The other temporal divisions employed include the Early Holocene, centred around 10, 000 years B.P., the Mid Holocene, with reference to the Mid Holocene Altithermal (MHA), a time period associated with the warmest conditions in Southern Africa, and placed at between 8000 and 6000 cal y B.P. (Partridge *et al.*, 1999).

The late Holocene period includes the period of time after the MHA to the present. A separate section is assigned to human impact which includes both the impact of pre colonial settlement, and colonial settlement to the present day. There are a number of issues to be considered which centre around the difficulty in comparing data derived from a wide variety of proxies to compare similar time periods. One of the difficulties is the wide geographical distribution of sites from which the data is derived, with regional inferences being made from a small number of widely distributed study sites. Caution should also be taken when comparing data derived from a wide variety of proxies, as this data could be seen as subjective as each proxy is subjected to different methods of interpretation.

Issues also arise in terms of various dating techniques which are applied to the different materials under scrutiny, as dating techniques have improved over time, some doubt has been thrown over the reliability of previous techniques, especially when applied to certain materials, i.e. the radiocarbon dating of calcretes and carbonates. As a result, data

derived from some of these older techniques may now be viewed as unreliable and of limited value, and care must be taken when using them for comparative purposes.

2.1.1 LGM

It would appear as if there are regional differences in palaeoenvironmental trends through the Quaternary, and evidence from various regions within the Southern and southwestern Cape during the LGM would seem to support this (Chase, 2005). Evidence from Vankervelsvlei in the Southern Cape, in what is currently a year round rainfall zone seems to indicate a period of increased aridity around the time of the LGM (Irving, 1998).While evidence from the southwestern coastal regions of the present day Winter rainfall Zone indicate cooler and moister conditions around the time of the LGM (Meadows and Baxter, 1999). The presence of ericoid and proteoid elements in the pollen spectra of *Hyrax* middens in the Cederberg (Scott, 1994; Scott and Woodborne, 2007a; Scott and Woodborne, 2007b), has been interpreted as an altitudinal lowering of vegetation belts, which in turn has been interpreted by Meadows and Baxter (1999) as evidence for a cooler and wetter LGM. While Parkington's (1986) study of macro and micro mammalian fossils from the Elands Bay cave deposits has been interpreted as a clear indication of drier conditions around 20 000 years B.P. (Deacon and Lancaster, 1988), a more recent study based on wood charcoal and pollen evidence from this cave suggests a cooler LGM associated with substantially more available moisture (Parkington *et al.*, 2000). The inferred moisture increase is based on evidence of increased representation of scrub forest taxa, including several afromontane elements in an area that

supports xeric asteraceous scrub in the present day (Parkington *et al.*, 2000). This conclusion accords with two other studies of the cave sediments (Allsopp, 1998; Baxter, 1996) which also point to an increase in available moisture around the LGM.

The most recent synthesis by Chase and Meadows (2007) agrees with the notion of a wetter than present LGM, but also cautions that it also appears to be a transition period exhibiting a general reduction in humidity over time. A large amount of variability over the LGM period has also been inferred (Scott and Woodborne, 2007a) as a study of the ratios of various key pollen types exhibits sharp variation. Scott cautions against making generalisations regarding conditions during the LGM. In contrast to the LGM environments at Elands Bay cave are those of Boomplaas cave, where palynological evidence points toward lower plant species diversity and increased representation of xeric taxa, thereby suggesting cooler, drier conditions through the LGM (Deacon *et al.*, 1984); such a conclusion is supported by size estimates on mammal fossils as well as the greater proportion of grazers as opposed to browsers, suggestive of open grassland environments (Klein, 1984).

The various bodies of evidence for the region offer further support for the notion that the climatic changes proposed in the western and southwestern parts of the WRZ were indeed out of phase with those proposed for the south eastern parts and, indeed, those of the interior and summer rainfall regions. This evidence is further supported by a more recent paper relying on near shore and marine records spanning the LGM. Gasse *et al.* (2008) suggests a drier southeastern Africa and moister southwestern Africa during the glacial, hinting at either stronger Westerlies or a northward migration of the Westerlies due to increased Antarctic sea ice extent.

2.1.2 Early Holocene

Palaeoclimatic evidence from different regions in the present day Winter Rainfall Zone (WRZ) show different conditions prevailing during the Early Holocene (see fig. 2.1). Evidence from the west coast at Elands bay based on both micro and macro mammal fossils, lends weight to the argument for a wetter early Holocene around 9600 years B.P. (Avery, 1983). This evidence is further supported by a study of fossil dune molerat sizes conducted by Klein, (1984). A subsequent study of dune molerat fossils at Bynekranskop also argues for the occurrence of wetter conditions *c.* 10 000 years B.P. (Klein, 1991). There is evidence for increased moisture availability from a number of sites in the southwestern parts, both from coastal and montane environments, where the onset of peat production in the early Holocene is recorded. Records from Sneeuberg, Driehoek and the Pakhuis Basin of the Cederberg (Meadows and Holmes, 1999; Meadows and Sugden, 1991) as well as the Cape Flats (Schalke, 1973) illustrate the onset of, or accelerated development of wetland organic sediment accumulation in the early Holocene. The aforementioned evidence seems to stand in contrast to other proxy evidence presented for the region, although once again caution must be taken when contrasting proxy evidence from different sources, with varied interpretations and possible discrepancies in dating.

A synthesis of various proxy data from Boomplaas cave would appear to indicate a number of climate fluctuations through the Holocene, and an interpretation of this data indicates the prevalence of warmer temperatures in the early to mid Holocene (Deacon *et al.*, 1983). These data are supported by fossil mammal remains from various other sites in

the southern and eastern parts of the WRZ and point to a warmer and drier early to mid Holocene when compared to late Holocene records (Klein, 1984).

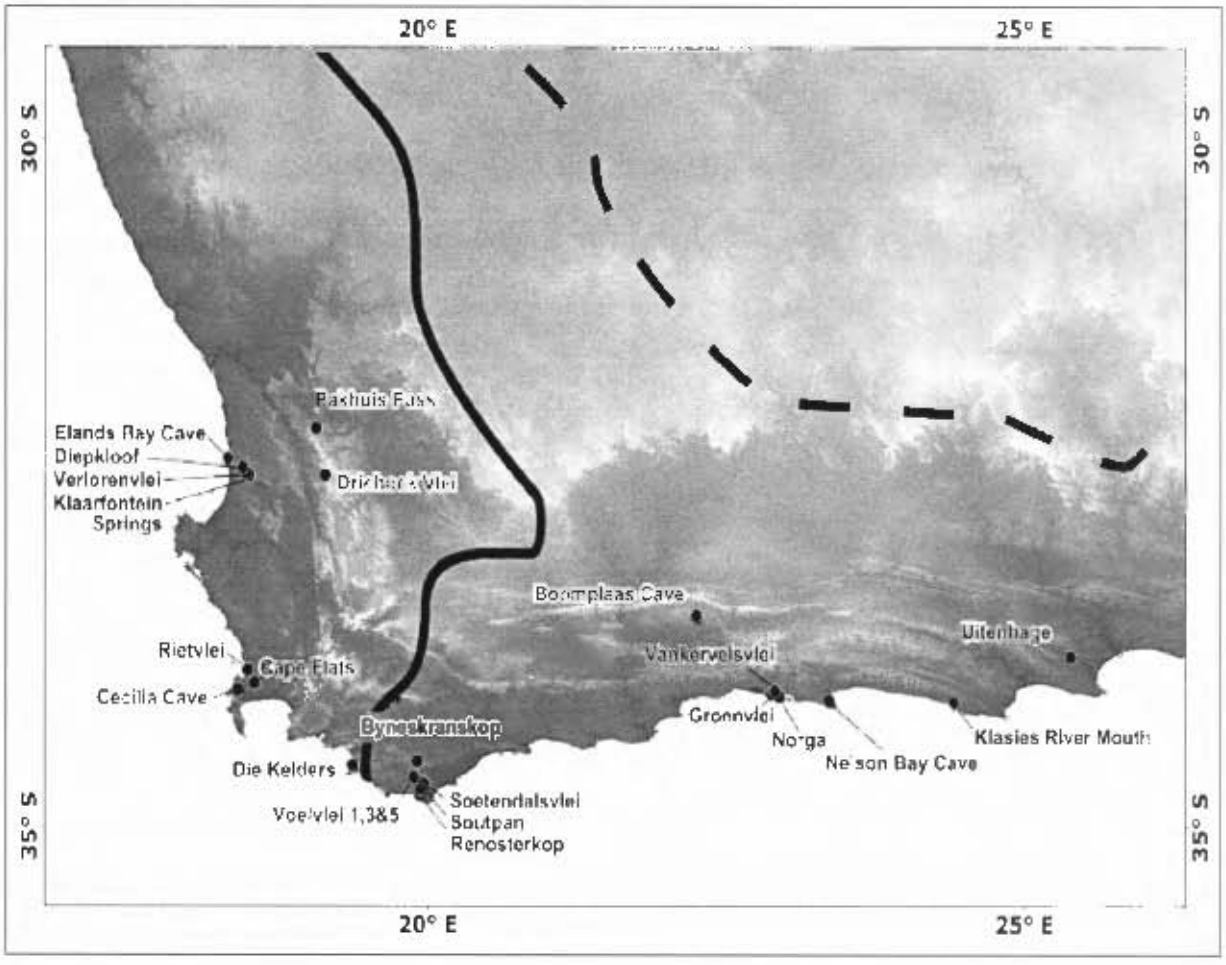


Fig 2.1 Palaeoenvironmental study sites in the Southern and Western Cape. The solid and dotted lines indicate the limits of the winter rainfall zone (WRZ) and summer rainfall zone, respectively. (From Chase and Meadows, 2007)

Deacon and Lancaster (1988) present a synthesis based on a number of data sets through which they conclude that the balance of evidence studied for the region indicates a drier trend in the early Holocene. Evidence from Cecelia Cave on the Cape Peninsula also points to drier conditions around 8300 cal yr B.P. (Baxter, 1989). Meadows and Baxter

(1999) in an overview covering the Late Quaternary for the region also lend support to the idea of a drier early Holocene in the southern and south-eastern regions. This argument is further supported by palynological studies from Groenvlei, where study of the pollen taxa indicates a drier trend in the early Holocene followed by more mesic conditions (Martin, 1968) in (Klein, 1980). A large body of the data presented for this region bolsters the argument put forward that the LGM may have been a transitional period with a general trend toward dryer conditions in the Late Glacial and following through into the Early Holocene (Chase and Meadows, 2007).

2.1.3 Mid-Holocene

As is the case globally (Meltzer, 1999; Smith *et al.*, 2002), the balance of palaeoenvironmental information indicates the mid-Holocene as the warmest period of the Holocene, with temperature maxima being inferred at a number of sites across the entire WRZ. There does, however, appear to be some contrast in evidence between these different parts of the WRZ in terms of moisture availability around the mid-Holocene period. Evidence of gaps in human occupation at Elands Bay cave around the mid-Holocene has been tentatively interpreted as an indication that warmer and drier conditions prevailed (Parkington, 1988). This evidence is supported by the study of molerat fossils from the same cave site which also suggest a drying trend (Klein and Cruz-Uribe, 1987; Klein and Cruz-Uribe, 1996) around this time. Palynological evidence from both Verlorenvlei, where xeric taxa are recorded between 6300 cal yr B.P. and 4500 cal yr B.P. and Klaarfontein Spring where the dominance of Asteraceae, Poaceae and

Chenopodiaceae is recorded is all indicative of a relatively arid environment during the MHA (Meadows *et al.*, 1994; Meadows and Baxter, 2001). The widespread mobilisation of aeolian deposits on the west coast around this time is also seen as an indication of a decrease in precipitation and resultant decrease in vegetation cover (Chase and Thomas, 2006). In contrast, evidence based on micromammalian fossils from Klipfonteinrand and Byneskranskop in the now all year round rainfall zone would seem to indicate an extension of the rainfall season in the winter rainfall region, with either warm wet winters or an increase in the proportion of summer rain in these regions around the time of the mid-Holocene (Avery, 1993).

A study of the pollen records from Groenvlei and Norga from the mid-Holocene indicate an increase in pollen frequencies of more xeric taxa (Martin, 1968). This increase has been interpreted as an indication of warmer conditions. This trend is supported by evidence of warmer water Diatom taxa at Groenvlei at this time (Martin, 1968). A synthesis of data presented by Chase and Meadows (2007) argues that there may have been an increase in summer rainfall in this eastern subregion, but a decrease in winter rainfall, which when coupled with the higher temperatures would have resulted in a region prone to drought during the MHA. In contrast, it has been put forward that conditions for forest expansion in the Southern Cape were at an optimum between 6000 and 2000 years B.P. as pollen records indicate this as the time period of maximum abundance of forest taxa (Deacon and Lancaster, 1988). Evidence presented by Deacon *et. al.* (1984) from Boomplaas cave suggest that the driest period of the Holocene can be found around 6500 years B.P., once again highlighting the contrast in mid-Holocene climatic conditions between the various regions making up the present day WRZ.

The exact timing of the mid-Holocene altithermal is also a topic of discussion, not surprisingly given the absence of strong chronological controls at many sites. Evidence from various sources would seem to confirm that the Holocene temperature maximum was reached some time between 8000 and 6000 years B.P. (Partridge *et al.*, 1999). While an oxygen isotope study of a speleothem from the Cango Caves places the mid-Holocene temperature maximum around 5000 years B.P. (Talma and Vogel, 1992). A synthesis of a number different proxies, presented by (Tyson *et al.*, 2001) places the MHA at around 7000 years B.P., with the semi-arid interior of the western regions experiencing increased rainfall and moisture availability with a drying trend toward the east. Perhaps the discrepancies in the timing of the MHA at the various study sites could be attributed to discrepancies in dating techniques used at the various sites to date the different proxy material, or could perhaps be an indication that certain regions acted climatically out of phase with other regions in the WRZ.

2.1.4 Late Holocene

The trend of the southwestern parts of the region behaving out of phase when compared with the southern and south eastern sections seems to continue in the Late Holocene period. Micromammalian evidence from The Elands Bay cave site would suggest moister conditions prevailing after 3000 years B.P. and also somewhat cooler temperatures (Avery, 1982; Avery, 1983). Evidence from both Klaarfontein Springs (Meadows and Baxter, 2001) and from Cecelia Cave (Baxter, 1989) supports the assumption of wetter, cooler conditions. This argument is further supported by Meadows and Baxter (1999)

whose synthesis of climate change during the Quaternary also seems to suggest a wetter late Holocene period, although the pollen record from Hangklip studied by Scott (1984) reveals insufficient evidence of the vegetation to enable inferences to be drawn as to the nature of changes in either temperature or availability of moisture during the Late Holocene.

An analysis of micromammalian fossils from De Kelders suggest that temperatures have been cooler in the last 2000 years (Avery, 1982, 1983). In the Southern region in what is at present day the all year rainfall zone, evidence indicates more mesic conditions coupled with all year round rainfall subsequent to the MHA as a result of the increased effect of the Westerlies. The reestablishment of forest taxa at the expense of more xeric taxa between 4500 cal yr B.P. and 2500 yr B.P. (Scholtz, 1986) is further supported by palynological evidence from Groenvlei (Martin, 1968) and Vankervelsvlei (Irving, 1998) indicating more mesic conditions at this time. This period of forest reestablishment is interrupted by a period of more arid conditions between 2700-1300 cal yr B.P. (Scholtz, 1986)and continues with forest expansion between 1800 cal yr B.P. (Martin, 1968) and 1300 cal yr B.P. (Scholtz, 1986). A synthesis of data from Boomplaas cave by Deacon *et. al.* (1983) indicates temperature fluctuations during the Holocene around the present day mean, but generally cooler temperatures prevailing in the last 2000 years. Samples obtained from a number of lunette dune sequences on the Agulhas Plain present evidence indicative of a number of relative wet and dry phases during the Late Quaternary. Periods of dune accretion are equated to conditions similar or drier than the present. A number of periods of dune accretion during the late Holocene at 2.7ka, 1.2ka and 800 years B.P. have been reported (Carr, 2004).

2.1.5 Human Influence

The role of anthropogenic disturbance during the more recent past has been commented on and put forward as an important factor contributing to vegetation change in the WRZ, however human occupation of the region dates back substantially further than recorded colonial settlement, or even the arrival of tribal pastoralists some time before that. Evidence from cave sites in the mountains of the Cape Fold Belt (Parkington and Hall, 1987) and at coastal sites such as Sixteen mile beach (Compton and Franceschini, 2005) show regular inhabitation by hunter gatherer tribes many thousands of years before the arrival of pastoralist herdsmen in the region. The impact that these hunter gatherer cultures had on the environment is thought to be very localised and minimal due to their small numbers and dispersed distribution and whole scale environmental impact by these early human communities is debatable (Meadows, 1998). Although these communities were capable of producing fire, there is no irrefutable evidence of the alteration of fynbos communities through palaeo-anthropogenic fires, although there is some circumstantial evidence that anthropogenic induced fires may have led to vegetation instability and periods of dune mobility at Elandsfontein in the western lowlands (Deacon *et al.*, 1983). Meadows and Sugden (1991) attribute evidence of the alteration of the abundance of certain *Protea* species in mountain fynbos and the reduction of an endemic cedar tree species (*Widdringtonia cederbergensis)* to environmental impacts by both hunter-gatherer and at a later stage, herder populations in the region. The near extermination of the already dwindling *Widdringtonia* population is also ascribed to

exploitation by colonial farmers as well as the increase in fire frequency resulting from their activities in the region (fig 2.2).

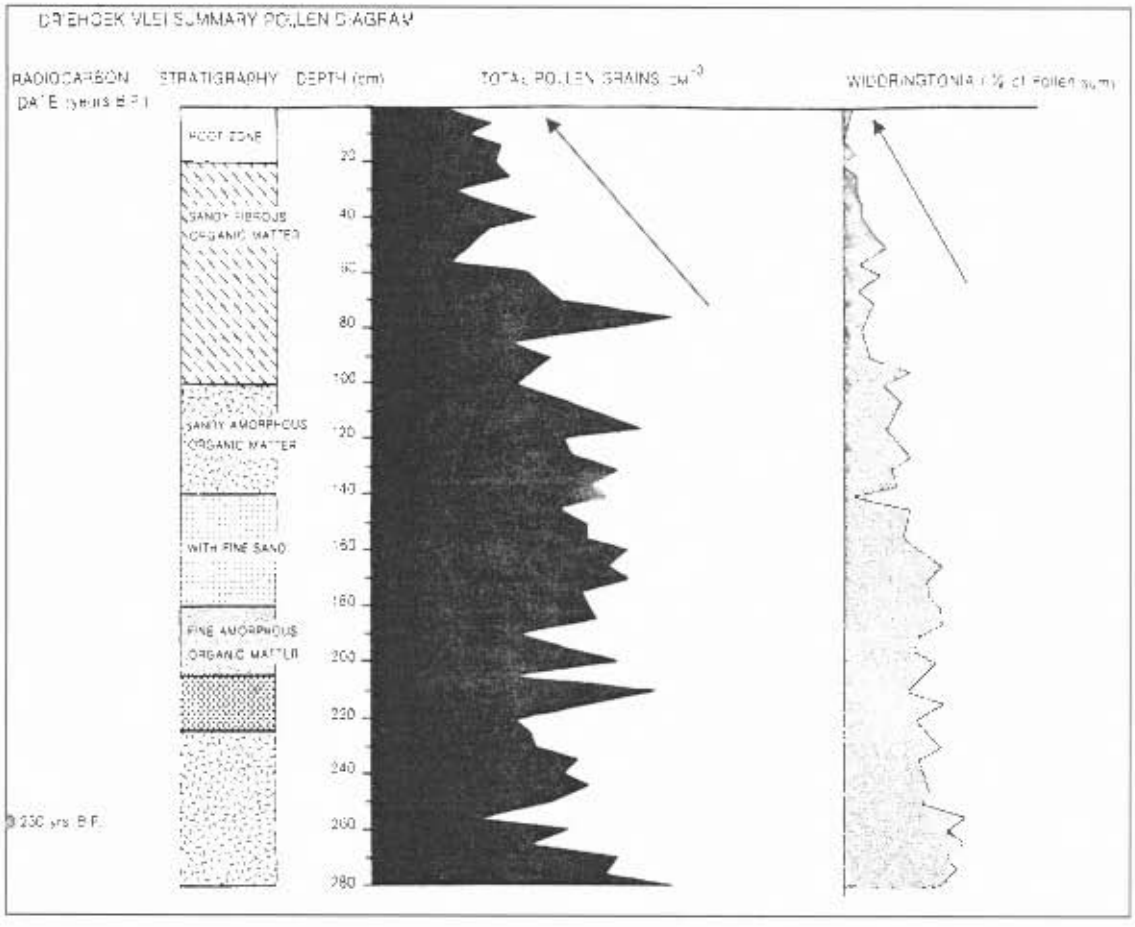


Fig 2.2 Evidence of Human impact at Driehoek, with decreasing numbers of *Widdringtonia cederbergensis* further reduced by human impact. (Sugden , 1989)

It is widely accepted that these pastoralist, herdsmen populations were present in the Western Cape from approximately 2000 years B.P. (Sadr, 1998). This arrival of herdsmen in the Western Cape heralded the beginning of a number of environmental changes in the region. Evidence from Klaarfontein Springs indicates a link between Khoi

Khoi pastoralism and the alteration of vegetation ecology during the last 2000 years. This evidence points toward the reduction in Poaceae and an increase in Asteraceae pollen from around 1900 yr B.P. (Meadows and Baxter, 2001)(see fig 2.3).

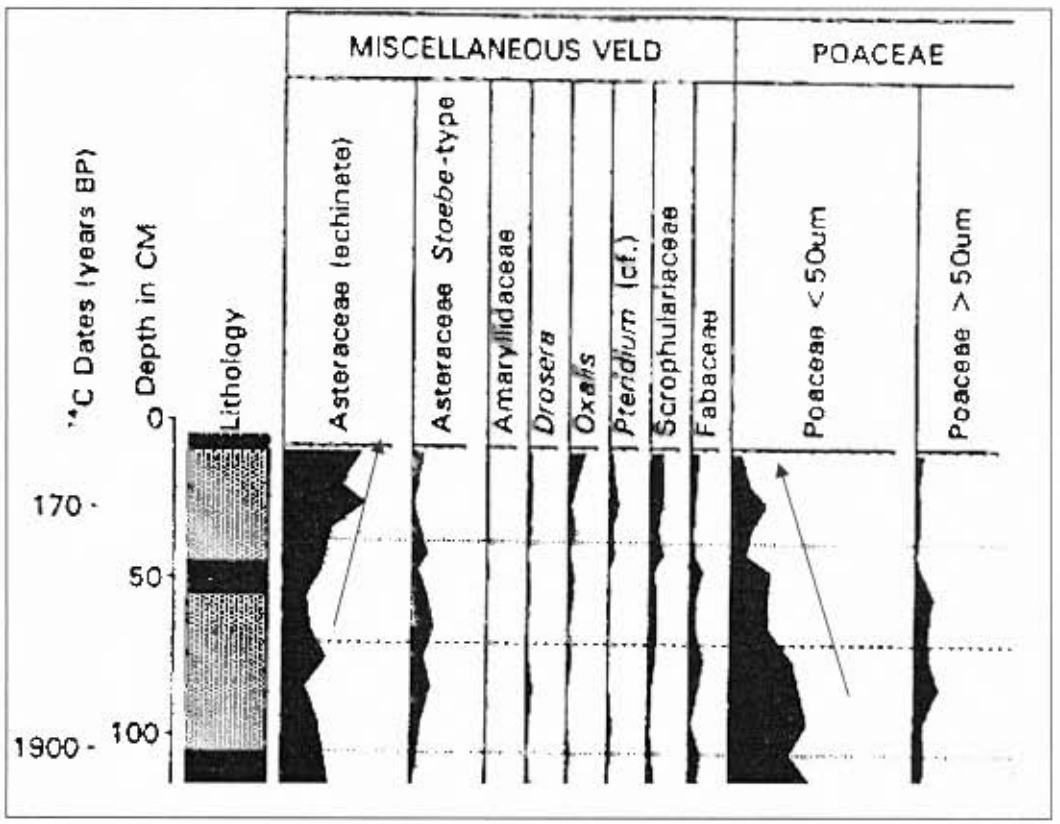


Fig 2.3 Evidence of prehistoric and colonial impacts on the environment at Klaarfontein Springs Meadows and Baxter (2001)

Further evidence is presented by Meadows and Sugden (1991) from the mountainous regions of the Cederberg. Due to the variations in geology in the region, and the subsequent variations in vegetation patterns, some regions seem to have been subjected to higher levels of environmental impact than others. The shale derived soils of the Western Cape, such as those derived from the Malmesbury shales, are more nutrient rich and these areas seem to have been the preferred grazing areas for these early pastoralists, while the

relatively nutrient poor sandstone derived soils and calcareous soils seemed to provide much less attractive pastures (Parkington, 1987). The availability of fresh water would also be a factor determining the spatial distribution of these pastoralists, and therefore the environmental impact incurred by grazing of large herds of livestock (Parkington, 1987), which by the mid seventeenth century may have numbered half a million cattle and a million sheep (Thom 1952). The most utilised area appears to be that area known as the West Coast Renosterveld, an undulating coastal plain running northwards from Cape Town (Kemper *et al.*, 2000). By far the most rapid and far reaching environmental impacts were experienced in the Western Cape subsequent to the arrival of the first colonial settlers from 1652 onwards, with the rapid expansion of the colony to the extent that by 1760 agriculture covered the entire region (Deacon, 1992). Evidence of this colonial settlement has been observed as far north as Verlorenvlei circa 1700, where evidence of the extermination of large mammalian fauna, overgrazing by domestic livestock and poor agricultural practices are evident in the palynological record (Baxter and Meadows, 1994)(see fig 2.4). The destruction of natural vegetation and the alteration of natural vegetation patterns post colonial settlement has occurred due to a number of reasons.

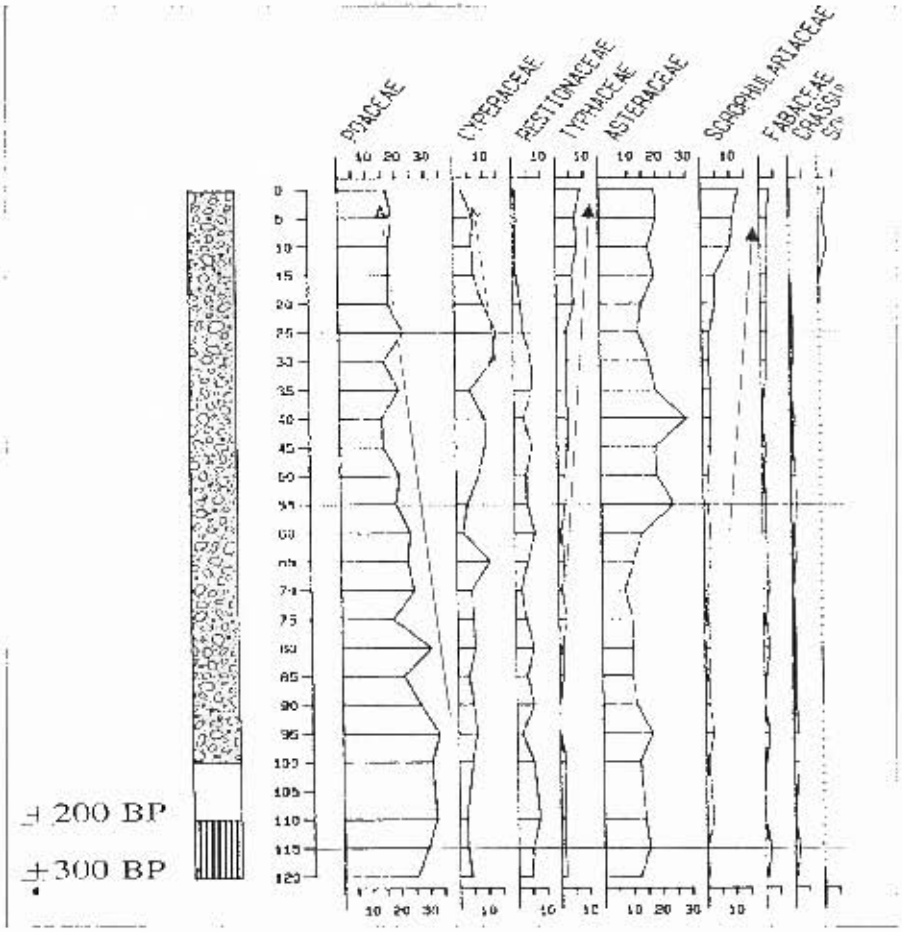


Fig 2.4 Evidence of post-colonial human impact at Verlorenvlei. (Baxter and Meadows, 1994)

Vegetation clearance is the largest contributor and visually the most obvious form of land degradation in the region (Meadows, 1998). Agriculture, particularly associated with grain production has resulted in the almost total clearance of Renosterveld, with upwards of 80% of this Fynbos type under agricultural cultivation (Kemper *et al.*, 2000). Clearance of natural vegetation has also resulted in the prevalence of large scale soil erosion, both through water and wind. Mountain fynbos communities have also been affected by agriculture, making way for vineyards and orchards of a range of fruit (Meadows, 1998). The introduction of invasive alien species, particularly post European

colonisation has had a marked effect on the vegetation patterns in the region. The intentional planting and natural dispersal of a number of trees and shrubs, particularly those belonging to the genera *Acacia, Hakea* and *Pinus* has lead to the widespread distribution of these highly invasive organisms. Subsequently a number of control measures have been implemented in recent times (Richardson and van Wilgen, 2004). These alien species were chiefly introduced in the mid eighteen hundreds for a number of reasons; including dune stabilisation, timber production, horticulture and even as botanical garden specimens (Meadows, 1998). These alien species are aggressive and ecologically successful, out competing natural vegetation, and leading to a general decrease in indigenous species diversity (Richardson and van Wilgen, 2004). The alien vegetation also implications with regard to fire, as higher fuel loadings in stands of alien vegetation results in larger, more intense fires, which in turn has implications for soil structure and chemistry which disadvantages indigenous vegetation. Dense stands of alien vegetation, with large biomass and leaf transpirational area, are known to consume far larger amounts of water than do stands of indigenous vegetation, which leads to significant impacts on catchment hydrology (Richardson and van Wilgen, 2004). This human disturbance makes it very difficult to interpret recent vegetation and ecological changes in terms of climate change, as the overwhelming changes brought on through anthropogenic activity tend to obscure the more subtle and temporally slower climatically induced signals.

2.2 Southwestern Australia

There have been numerous investigations into the Quaternary palaeoenvironments of Australia (Bowler, 1982; Colhoun, 1988; Kershaw *et al.*, 1991). However, the focus of the vast majority of these investigations have been the Eastern and South Eastern region of the continent (Zheng *et al.*, 2003b). The information concerning the region and time frame that is the focus of this thesis, namely the late Quaternary in southwestern Australia, is sparse and data obtained through varying proxies is often conflicting. There is also the problem of a lack of continuous long term datasets spanning the Late Quaternary, or even the complete Holocene for the southwestern region of Australia. Data that has been gathered is also from a wide variety of proxies and as such is open to different interpretations, often making comparison between data sets very difficult. The improvement in dating techniques means that more recent reviews of previously examined study sites often yield different results, and therefore varying interpretations. Data concerning the southeastern or southern regions of the continent can also not be automatically extrapolated to include the South West of the country, as this southwestern region would appear at times to have experienced conditions different to those of other southerly regions studied. A key element contributing to climate change in what is presently a mediterranean climate region in southwestern Australia would be the position of the Southern Hemisphere westerly wind belt and the contributing pressure systems (Shulmeister *et al.*, 2004). Although climate change is one of the key factors leading to vegetation changes in the region throughout the Quaternary and indeed predating the Quaternary, a number of other factors such as fire frequency and sea level fluctuations

are thought to have played a major role and in the much more recent past, the effect of human interaction with the environment is also key to understanding vegetation change (Dodson, 2004; Dortch, 2004).

As with the data presented previously dealing with this time period in the Western Cape, South Africa, the data here are also dealt with in various sections dealing with specific periods of time. A section dealing with human impacts in the region is also presented separately.

2.2.1 LGM

The balance of evidence for the greater part of the Australian continent around the LGM would appear to indicate that climates were drier and/or cooler around this time leading to an extensive period of dune building in inland Australia. This poleward extension of the arid zone extended as far south as Northern Tasmania (Bowler, 1983; Colhoun, 1993; Wasson, 1986). This evidence is further supported by palaeo lake level data, which indicates lower lake levels in the Australian interior around 18 000 yr B.P., with a continuing drying out with the time of maximum aridity being centred at 12 000 yr B.P. Furthermore, low lake levels would appear to have been characteristic of southwestern Australia during the late glacial around 15 000 yr B.P. (Harrison and Dodson, 1993). Aeolian and lacustrine evidence from a couple of lake systems in southwestern Australia show a period of lunette dune building centred around the LGM, thus supporting the hypothesis that the sub-tropical high pressure cells intensified and shifted southward, thereby displacing the Westerlies, leading to a drier phase in the region (Zheng *et al.*,

2003a). This argument however is not always supported by palynological evidence from the region. Palynological evidence has indicated that although the climate in southeastern Australia around the time of the LGM was sufficiently different from today to have suported different vegetation characteristics to today, the same cannot be said for southwestern Australia. Evidence would appear to indicate that the heathland and shrubland dominant in modern times, were indeed the dominant vegetation types around the LGM (Dodson, 2001). It would seem evident therefore that care must be taken not to automatically extend syntheses of data and resulting conclusions from the rest of the southern regions of Australia to include the southwestern Australian region.

2.2.2 Early Holocene

Evidence would seem to suggest an increase in rainfall in the Southern Australian region in the post glacial period of the early Holocene. Harrison and Dodson (1993) have attributed this increase in precipitation to the northward migration of the southern margin of the sub-tropical anti-cyclone belt, leading to all year round effective penetration of the Southern Hemisphere Westerlies. A counter to this suggestion, is that of the southward penetration of the North Australian monsoon, which led to increased summer rains, and therefore increased annual effective precipitation (Shulmeister, 1999; Singh and Luly, 1991). Evidence from southwestern Australia to support increased precipitation in the early Holocene can be found at Tunnel Cave in the Leeuwin –Naturaliste Park. Macroscopic charcoal remains indicate a change in the canopy trees of the area, indicative of an increase in rainfall and continued vegetation encroachment until the mid

Holocene. Faunal fossil remains (lizards and other small vertebrates) from the cave site also appear to support the suggestion of increased rainfall and resultant vegetation encroachment. In contrast to this, is palynological data from a site called Loch Mc Ness. Evidence from this site dating as far back as 9000 yr B.P. suggests only minor changes in vegetation, and that these small vegetation shifts cannot be ascribed with any amount of certainty to climate change (Newsome and Pickett, 1993). There is support for this latter argument from palynological and geochemical evidence from Two Mile Lake in southwestern Australia which indicate that vegetation patterns were either unresponsive to, or unchanged by climate change during the early Holocene (Itzstein-Davey, 2004).

2.2.3 Mid Holocene

A number of studies dating back to the mid Holocene period have been undertaken using a range of different proxies (see fig 2.5). These studies have provided what is often seen as very conflicting data, and as such, a complete reconstruction of the environments in southwestern Australia remains a matter of debate (Zheng *et al.*, 2003a). While no definitive pattern has emerged from the southern regions of Australia, an inferred mid to late Holocene drying out period in Southern Australia can be explained either in terms of a decline in the Westerlies, or as a decline in the influence of the northerly monsoonal moisture input (Shulmeister *et al.*, 2004).

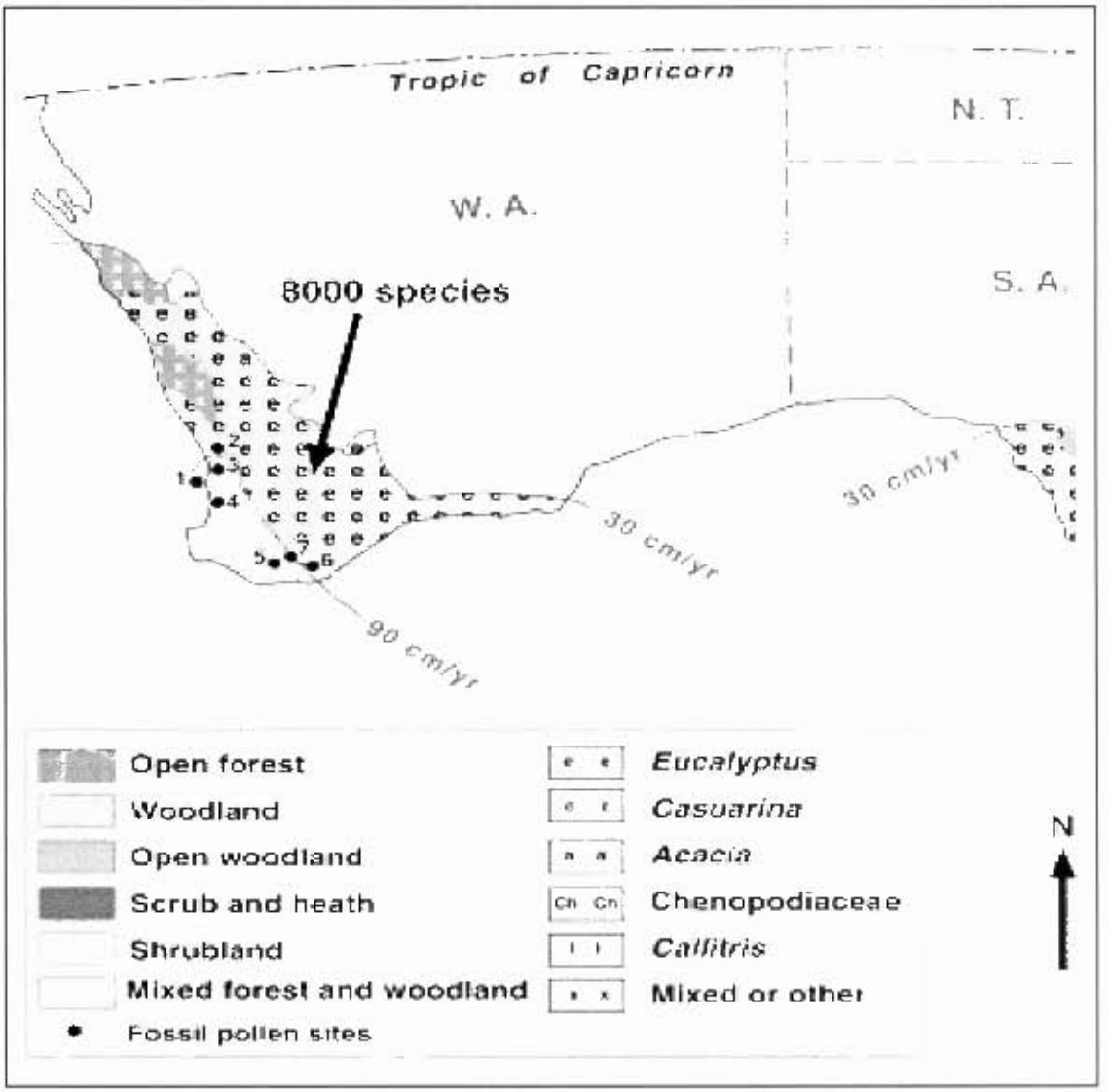


Fig 2.5 Map illustrating south west Australian Winter Rainfall zone and Palaeoenvironmental study sites (after Dodson, 2001). 1) Rottnest Island 2) Loch Mc Ness 3) Perth coastal plain sites 4) Myalup Swamp 5) West Lake Muir 6) Weld Swamp 7) Byenup Lagoon

Mid Holocene evidence from southwestern Australia includes the pioneering work of Churchill (1968), which was the first comprehensive palynological study undertaken in the region. A study of sediments from Boggy Lake provides a continuous record from 6000 years B.P. Churchill's (1968) conclusions, reached through the interpretation of

varying ratios of two *Eucalyptus* species, was that of substantial fluctuations in effective rainfall through the mid to late Holocene, with a wetter period between 6000 and 4500 years B.P. followed by a gradual decrease in effective precipitation. A re-examination of the Boggy Lake sequence as well as the examination of the Loch Mc Ness sequence by Newsome and Picket (1993) shed some doubt on the Churchill (1968) study, and found only minor changes to vegetation over this period of time, which they once again failed to ascribe to climate change. Instead they suggested that sea level fluctuations had a greater effect on vegetation shifts, and that perhaps the shifts in vegetation were merely a reflection of the fluctuations in the water table. Dortch (2004) ascribes the mid Holocene extinction of *Petrogale lateralis* (the black flanked rock wallaby) at tunnel cave to vegetation encroachment due to an increase in effective precipitation.

A number of other studies undertaken in the southwestern Australian region have relied on proxy data other than palynological studies. A study of the distribution of molluscs, ostracodes and forams in what is now the modern Swan River estuary, presents evidence indicating reduced fresh water discharge and an inferred drier period dated between 6100 and 4000 years B.P.(Kendrick, 1977; Yassini, 1988). Paleao lake level data presented by Harrison and Dodson (1993) also provides evidence to support this claim, with lower lake levels apparent around 6000 years B.P. A study by Semeniuk (1986) relies on the study of groundwater calcrete development in the Perth Basin under specific climatic conditions to infer changes in past climates. The results of this study implies that the mid to late Holocene (6000 – 2800 years B.P.) was semi- arid, to arid over most of the southwestern region (Semeniuk, 1986). This suggestion is once again challenged by the

studies of Newsome and Picket (1993) who claim that based on fossil pollen data, no inferences can be made with certainty about climatic conditions.

2.2.4 Late Holocene

Once again, evidence from southwestern Australia with regards to the Late Holocene is not very extensive and at times contradictory. Churchill's (1968) study of the relative frequency of *Eucalypyus diversicolor* indicated an increase in relative abundance around 2500 years B.P. He correlates this with an increase in relative precipitation around this time. Dortch (1997) discusses the effect that increased seasonality in the Late Holocene had on Aboriginal fisheries in the region, with estuaries experiencing seasonal salinity and seasonally increased sediment loading. Semeniuk (1986) provided evidence for an extended arid period running from the mid Holocene, and only abating around 2800 years B.P. after which a more humid climate similar to present day prevailed. Evidence of lower lake levels in southwestern Australia around 3000 years B.P. would seem to support this theory (Harrison and Dodson, 1993). Evidence from Byenup Lagoon near Manjimup in southwestern Australia seems to indicate an increase in effective precipitation around 4800 years B.P. which led to the initiation of peat development (Dodson and Lu, 2000).

The commencement of peat accumulation at other southwestern Australian sites around this time (Churchill, 1968) would seem to echo this suggestion. Dodson and Lu (2000) attribute this increase in effective precipitation to a more effective westerly wind stream in the late Holocene. They also make the point that changes in vegetation patterns since

4800 years B.P. are more likely to be a result of changes in fire regimes and through plant interactions that through climate change. These sentiments agree with Newsome and Picket's (1993) Boggy Lake study, where evidence suggests that although minor vegetation changes have taken place over the last 4500 years, they cannot be confidently attributed to climate change. Dodson's (2001) study raises the point that although fire has been an important component of the ecology of southwestern Australia, it is still not clear as to whether fire played an important role in vegetation change through the Holocene period. What is evident, however is the major role that European settlement over the last approximately 200 years has had on vegetation change and the environment in the region as a whole with key issues such as agricultural practices, vegetation clearing and resulting ground water and salinity issues.

2.2.5 Human Impact

The timing of the arrival of Aboriginal people in Australia remains a topic of much discussion, with dates for the earliest occupation ranging from 40 000 B.P. to 120 000 B.P. being put forward (Bowman, 1998). Although dates for the earliest occupation in Australia remain open for debate, there is clear evidence that Aboriginal occupation in Western Australia can be traced back to at least 40 000 B.P. (Pearce, 1981). The subject of much contention in the region is to what effect these Aboriginal cultures had on the environment, with particular regards to fire and vegetation alteration as a result thereof. There is no debate that Aboriginal cultures used fire as a tool for maintaining vegetation suitable for certain herbivores and food plants, hence the term "fire-stick" farming, but it seems that there is no unequivocal evidence to prove that these practices had long term

effects on vegetation diversity, soil erosion or the destruction of the Australian megafauna or that the Aboriginal cultures had any predictive ecological knowledge concerning the long term effects of these practices (Bowman, 1998). In fact, the subsequent reduction in Aboriginal burning has been put forward as a possible cause for the extinction of members of the Australian fauna (Short and Smith, 1994), although this alteration of the fire regime at the same time as the megafaunal extinction remains a topic of debate. Anecdotal evidence from the diaries of early settlers in southwestern Australia report on frequent burning of forests and woodland areas by Aboriginal inhabitants, leading a number of authors to conclude that this fire regime replaced the by now extinct megafauna in maintaining low vegetation, open woodlands and forests (Flannery, 1994). This evidence is also subject to debate, and the reliability of these records questioned, with claims of exaggeration of the frequency and impact of these fires.

The paucity of artefacts and charcoal remains in these southwest forests has been interpreted as evidence of a lack of occupancy in these forests as far back as 5000 B.P. (Dodson, 1992), although evidence of Aboriginal settlement at various sites in the Leeuwin- Naturaliste area dating back as far as 27 000 B.P. have been recorded (Dortch, 1979). More recent Aboriginal fishing activity along the coastline has been dated to 7000 B.P. (Dortch, 1997).

A high resolution Pliocene pollen and charcoal record from a meteor impact crater at Yalallie in southwestern Australia has provided evidence that vegetation types were not too dissimilar to those found today, and that fire played a role in the landscape a long time before the arrival of Aboriginal cultures, with fire frequency intervals only slightly shorter than those experienced post Aboriginal inhabitation (Atahan *et al.*, 2004). What is

evident is that large scale environmental impacts in the region commenced with the arrival of Colonial settlers in 1829 and the activities associated with this colonial culture (Conacher, 1998). Loch Mc Ness, North of Perth also exhibits pollen trends possible associated with human impact, such as the decrease in Poaceae, Cyperaceae and *Casuarina* sp. pollen. (Newsome and Pickett, 1993)(see fig 2.6).

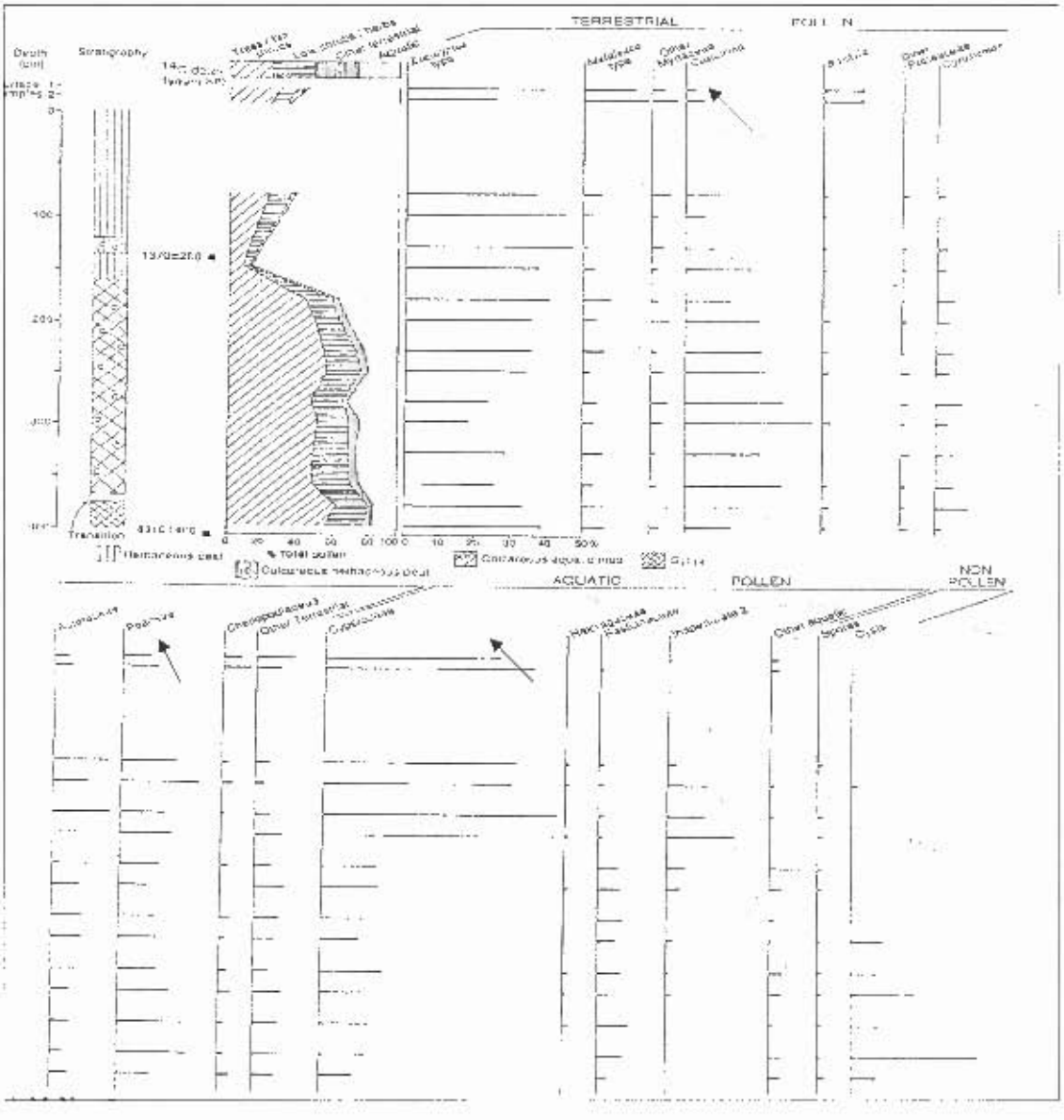


Fig 2.6 Pollen diagram from Loch Mc Ness illustrating possible human impacts. (Newsome and Pickett, 1993)

The greatest post colonial impacts on the environment in southwestern Australia are all associated with various forms of agriculture in the region (Hobbs, 2001). Evidence recorded in the southwestern forests, indicates a reduction in fire frequency after the arrival of colonial settlers, corresponding to the reduction in numbers of Aboriginal people in the region, as well as intense wild fires as a result of increased logging in these forests (Ward *et al.*, 2001). A number of important land degradation issues have stemmed from this increased land use in the region. An important issue is that of the loss of natural wetlands, with almost 70% of natural wetlands on the coastal plain in southwestern Australia being lost since the arrival of Colonial settlers in 1829. These wetlands have been lost primarily to draining and infilling to make way for agriculture or urban expansion (Davis and Froend, 1999). This loss of wetlands has resulted in alteration of vegetation communities and the loss of many other wetland fringe communities.

Remaining wetlands are also under threat from another key issue resulting from agricultural practices, namely salinisation. With the removal of deep rooted natural vegetation, and the planting of shallow rooted agricultural crops, a rising, saline water table resulted (Williams, 1999). This increase in salinity has had marked effects on vegetation surrounding water sources, with the alteration of the natural vegetation in favour of salt tolerant species at the expense of naturally occurring wetland fringe and riverine species (George *et al.*, 1999). Agriculture has also had a marked affect in terms of fragmentation of the natural habitat, with small islands of natural vegetation remaining amongst vast tracts of agricultural land. Grazing on both natural vegetation as well as cultivated areas has also made a marked impression on species composition and

distribution in the region, while the introduction of alien species both faunal such as Rabbits, foxes and feral cats, and floral such as various grasses and trees such as *Pinus* sp. (see fig 2.7) have also served to further alter the natural landscape (Dodson and Lu, 2000; Hobbs, 2001).

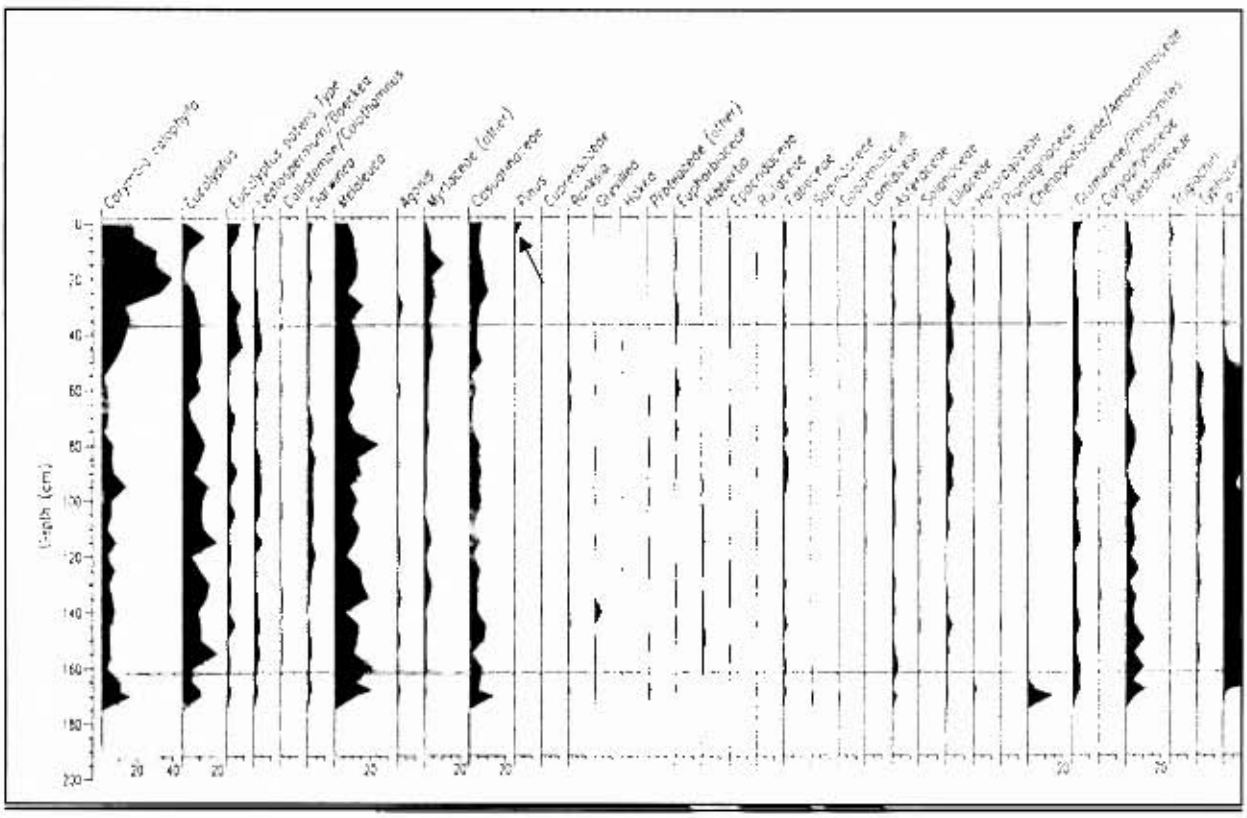


Fig 2.7 Pollen diagram from Byenup Lagoon, indicating *Pinus* in the pollen assemblage. (Dodson and Lu , 2000)

It is evident that activities that have had the greatest impacts on the natural vegetation in the region have taken place over the last couple of centuries, following the arrival of colonial settlers in the region. By 1986, approximately 55% of *Banksia* woodland on the Swan Coastal Plain had been cleared for reasons associated with agriculture, industry or urban expansion (Lamont *et al.*, 1995). This clearing has also paved the way for the

introduction of exotic, alien weed species and fungi (in particular *Phytophthora cinnamomi)* into the area, while alteration of fire regimes construction of roads, pipelines and other infrastructure have also placed huge pressure on the remaining natural vegetation (Hopper and Muir, 1984). It is clearly evident that agricultural practices that have been developed worldwide and imposed on a fragile ecosystem have had a devastating effect on the natural environment necessitating the development of locally appropriate conservation methods for the region (Hopper, 2003).

2.3 Global events in the Late Quaternary

There are a couple of events recorded in the Late Quaternary, evidence of which may be recorded globally in environmental proxy records. Evidence of these events may provide useful markers with regards to temporal placement of palaeoenvironmental records as the dates of these events are well documented. The first of these events is known as the Younger Dryas. This event is characterised by a period of rapid cooling at the end of the last glacial, lasting a few centuries (see fig 2.8)(Alley, 2000). A further event which may be of interest is the rapid cooling event centred around 8200 B.P. (Clarke *et al.*, 2004; von Grafenstein *et al.*, 1998). This rapid cooling event is thought to be a climatic response to a large outburst of fresh water into the North Atlantic as a result of the emptying of palaeo-lake Agassiz.

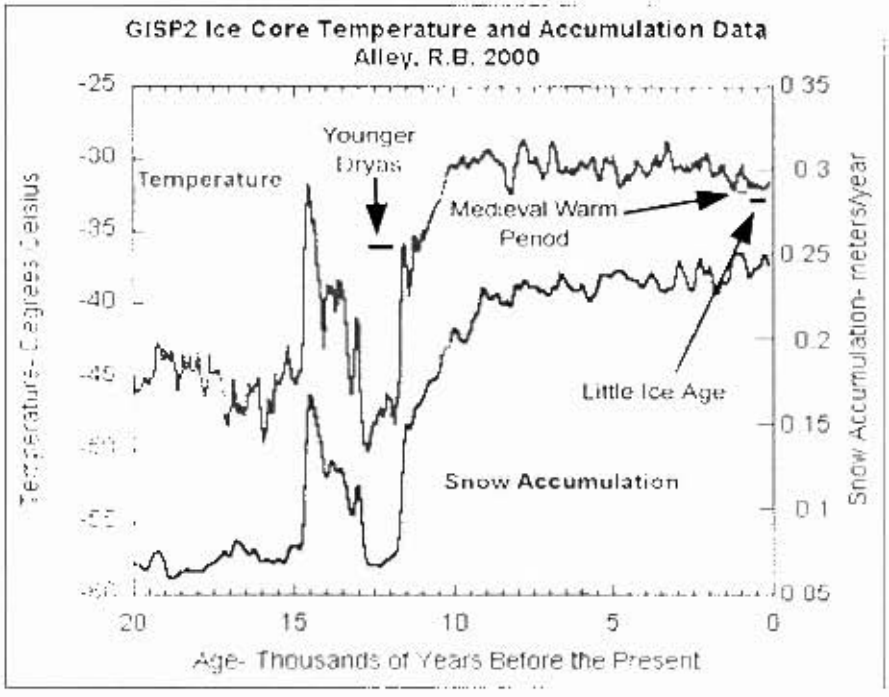


Fig 2.8 Younger Dryas event observed in GISP2 Ice core data. (Alley, 2000)

This event is similar in nature to the Younger Dryas, but half the amplitude (see fig 2.9). It brought about cooler, drier conditions in the Northern Hemisphere, leading to a displacement of vegetation patterns.

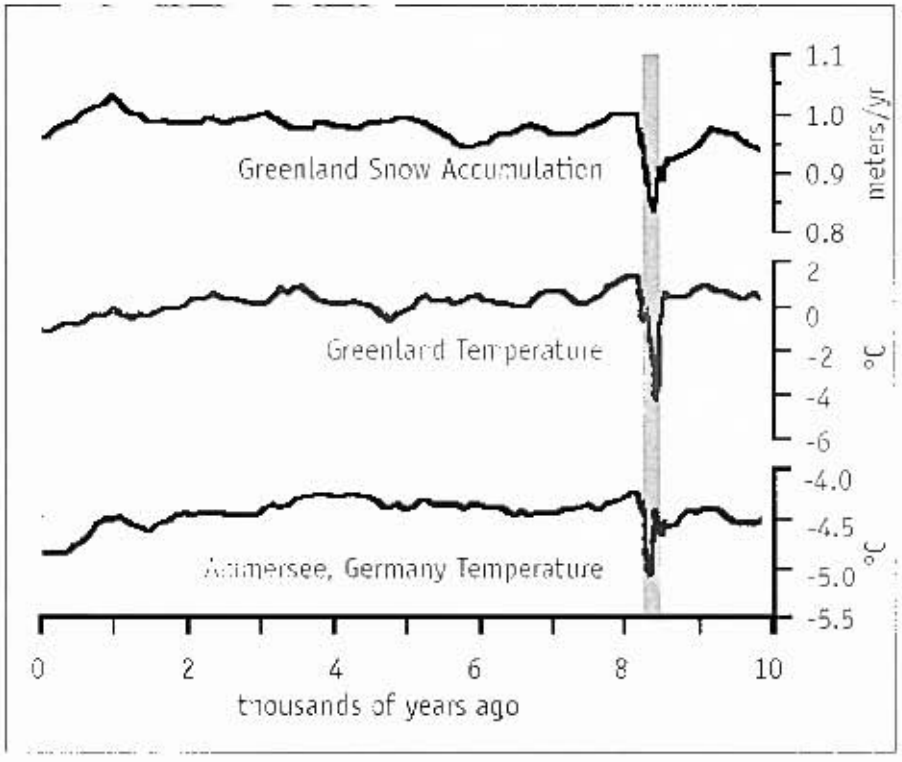


Fig 2.9 Evidence for 8200 B.P event. (von Grafenstein, 1998)

Whether there is evidence of this event in southern hemisphere palaeoenvironmental records remains a subject of debate, with some evidence from southern Africa (Smith *et al.*, 2002) suggesting that the 8200 B.P. event may have been a global phenomenon rather than one which may have been regionally constrained.

Chapter 3: Site Descriptions

Regional Setting

3.1 Western Cape

The Western Cape region occupies an area at the most south westerly tip of the African continent. It is synonymous with the terms Fynbos Biome and the Cape Floristic Region. The Fynbos Biome is a biophysical unit dominated by sclerophyllous vegetation and fire controlled ecosystem processes. This Biome contains a number of types of fynbos and Renosterveld. The Cape Floristic region is a floristic term defined as the area of the subcontinent containing fynbos, and including afromontane forest areas (Rebelo, 1996). This region generally falls within the winter rainfall area and to some extent the all year round rainfall area to the east. This winter rainfall region is bounded to the north and the north west by more arid regions, while further along the East coast, it is bound by summer and all year around rainfall regions. It is bound by the Southern Atlantic Ocean to the west and by the Indian Ocean to the South East (see fig.2.1).

3.1.1 Geology

The region is dominated by three major rock types, namely the Malmesbury Group Shales, The Table Mountain Group Sandstones and the Cape Granites (fig3.1). These Rock types span a very long geological history with the Pre Cambrian Malmesbury

Group Shales being deposited some 800 million years ago. This group consists predominantly of low grade metamorphic rocks such as phyllitic shales, quartz and sericitic schist, greywacke and siltstones (Reid *et al*, 1999).

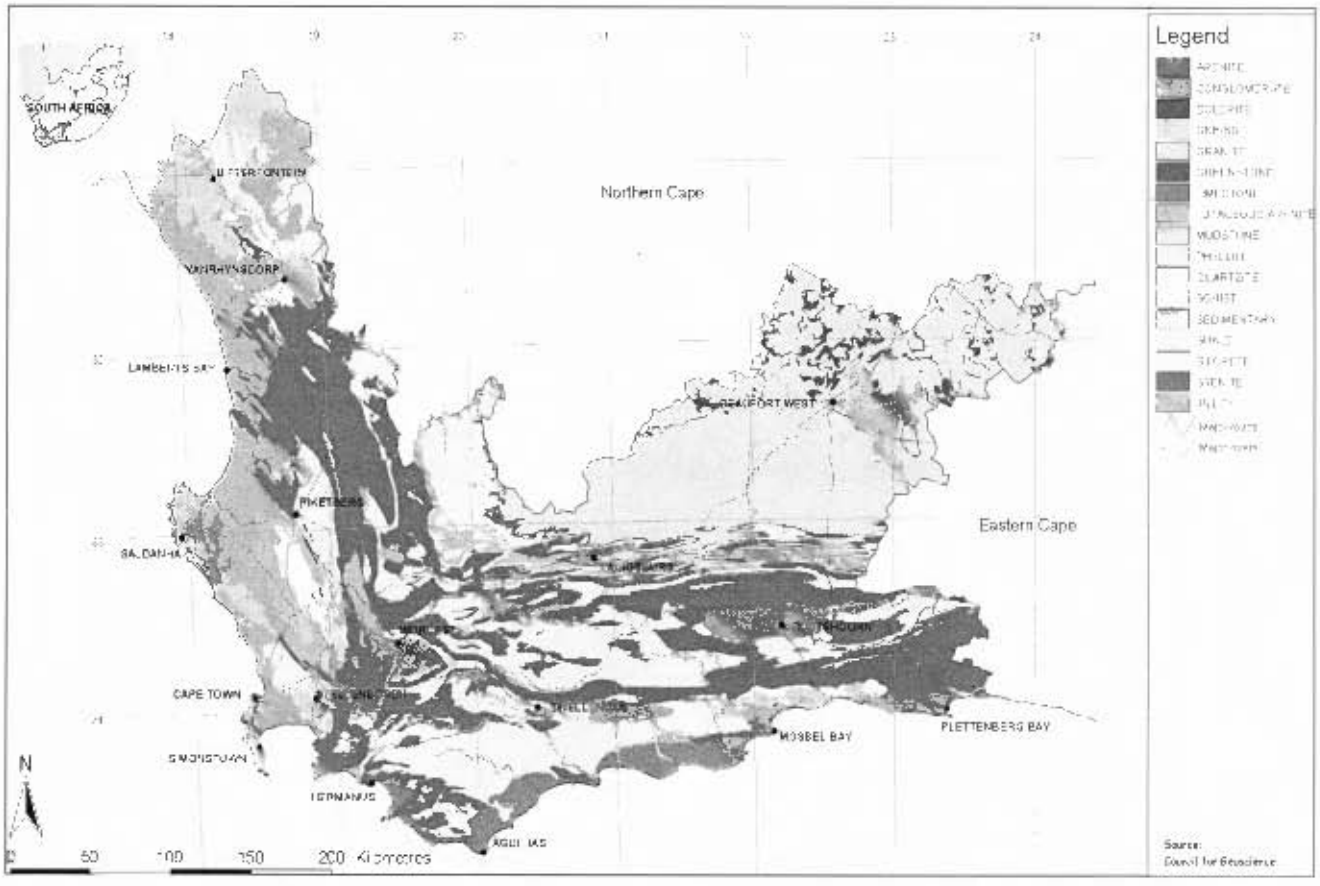


Fig 3.1 Geology of the Western Cape (South African Council for Geoscience)

This group is fairly susceptible to weathering, resulting in low relief landforms. The Granites formed beneath the Malmesbury shales around 640 million years ago, and areas where it is exposed are areas where the overlying Malmesbury Group Shales have been stripped off by various erosional agents. The Table Mountain group Sandstones were deposited on this eroded Granite Basement approximately 450 million years ago, as sand,

silt and mud deposits were lithified by pressure and then folded into the Cape Fold Belt. More recently, advances and retreats in sea level have left large areas of the Cape Peninsula blanketed in weakly cemented marine sands as well as aeolianites and calcareous dune features such as the Velddrif and Witzand formations. Soils of the Western Cape are generally associated with the parent material from which they are formed, with nutrient poor, light coloured, highly leached soils being associated with the quartzitic sandstones of the Table Mountain Sandstone group (Theron, 1983). Nutrient poor soils are also found on the drift sands of the west coast area. More nutrient rich, darker soils are formed on the shales and phyllites of the Malmesbury and Graafwater Groups. In isolated areas with granitic outcrops, deep kaolanitic soils are also to be found. Long term evolution of these soils has also lead to the formation of ferric or silicious duricrusts in the region (Conacher, 1998; Theron, 1983).

3.1.2 Regional Climate

Much of the Western Cape (and indeed the Fynbos Biome) falls within a region typified by wet, cooler winters and warm, dry summers. This region can also be classified as experiencing a mediterranean-type climate. Rain in the region is spatially highly variable, with maximum annual rainfall in excess of 2000mm in certain areas, and as little as 200mm per annum in other areas (Tyson and Preston-Whyte, 2000). Most of the rainfall in the region is brought by frontal activity associated with winter mid latitude cyclone development in the South Atlantic. In the winter months, the amplitude of the disturbance in the westerly wind belt is increased, moving the cyclone development further north.

This in turn leads to frontal activity associated with cyclonic activity being shifted further north. These cold fronts routinely move across the Western Cape bringing cooler weather and associated rain (Preston-Whyte and Tyson, 1993). During the summer months, the cyclonic development migrates further south, reducing the effect of the frontal activity on the Western Cape, hence much reduced rainfall. Regardless of this north and south seasonal migration, the centre of these cyclonic systems remains south of the Cape with only the tails of the frontal systems making landfall. Hence there is a rainfall gradient, with reduced rainfall as one moves further north and inland from Western Cape (fig 3.2).

Other sources of precipitation include occasional cut off low pressure cells forming during spring and autumn on the coast which serve to channel moist oceanic air over the land (Tyson and Preston-Whyte, 2000). Due to the topography of the region, in particular the proximity of mountain ranges to the coast, orographic rain supplements localized rainfall and runoff where moist air is forced up and over topographic features. To a lesser extent, coastal fog may also supplement coastal moisture availability, although this fog does not tend to penetrate very far inland, and its effect is constrained to a narrow coastal belt.

Climate data for four locations within the region are given below. Clanwilliam is an inland site, and the most northerly of the four sites. It is near the boundary of the fynbos biome and the drier Karoo biome. Langebaan is a coastal site to the north of Cape Town. George is a coastal site much further to the east, and falls within the all year round rainfall zone. There is not much variation in the average maximum summer temperatures, but it can be observed that the minimum temperatures at Clanwilliam both in January and

July are lower than those of the other three sites. This is due to altitude and distance from the coast, with Clanwilliam away from the temperature moderating effects of the ocean

Table 3.1 Climate data for selected sites in the Western and Southern Cape (SA. Bureau of Meteorology)

Site	**Ave. Temp January Deg. C.**		**Ave. Temp. July Deg. C**		**Ave Monthly Rainfall mm**	
	Max	Min	Max	Min	Jan	July
Clanwilliam	27	11	13	2	6.3	32.1
Langebaan	28	15	18	7	8	47
Cape Town	26	16	18	7	15	82
George	25	15	18	7	63	43

The rainfall figures also illustrate the dominance of winter rainfall in the region, with the exception of George, where the rainfall can be seen to be more evenly spread over the seasons. The rainfall data also suggests that rainfall generally increases as one moves further south west in the region. These general rainfall and temperature patterns are greatly complicated by the relief of the region, with the prolific mountain ranges giving rise to complex microclimatic variations, all of which have a strong influence on vegetation distribution patterns in the region.

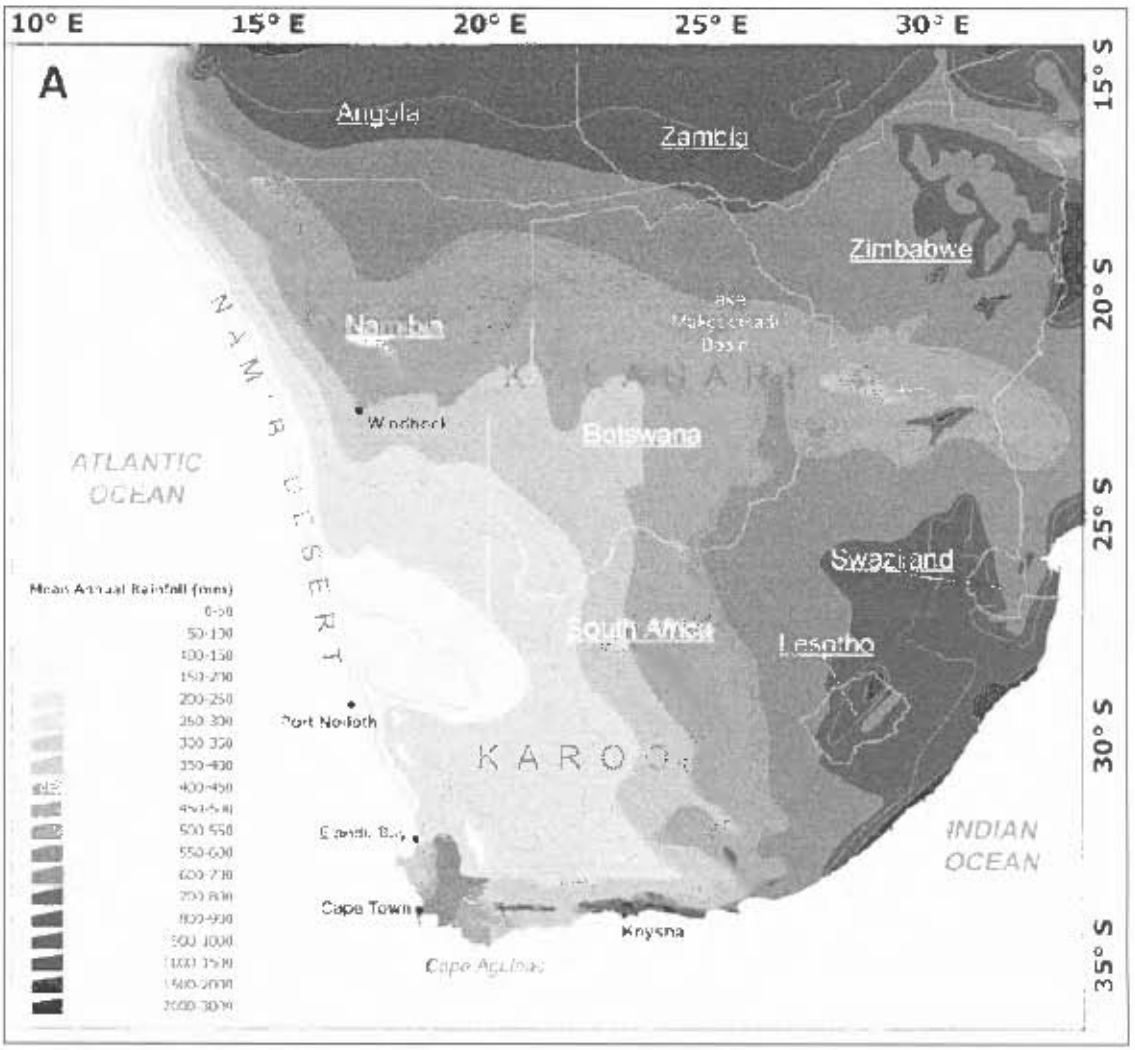


Fig 3.2 Annual rainfall for southern Africa (From Chase, 2006)

Temperature variation within the Western Cape is influenced by both distance from the coast and topography (Fig 3.3 and 3.4). Temperatures of regions immediately adjacent to the coast tend to be moderated by cool sea surface temperatures, in particular the West coast with cooler Atlantic sea surface temperatures as opposed to the Southern and South east coast with The Indian Ocean sea surface temperatures a few degrees warmer on average.

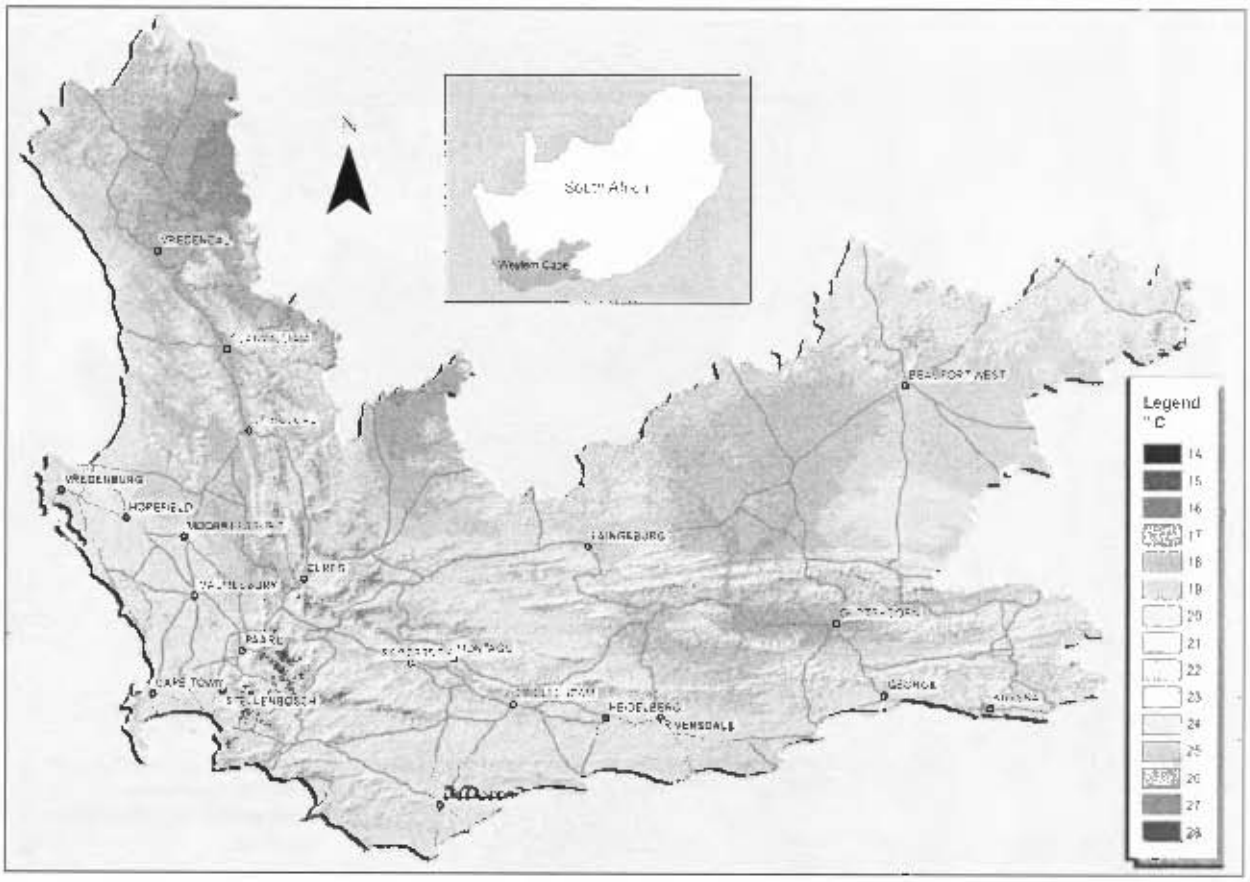


Fig 3.3 Mean temperature maximum for the Western Cape. (Western Cape Department of Agriculture, based on Schultze (1997)

Further inland as effect of the coastal waters diminishes, temperatures may reach 40 degrees Celsius in the summer months, and below freezing in the winter months, where snow on the higher peaks of the Cape Fold Mountain belt is not uncommon during winter. Diurnal temperature ranges also tend to be more extreme in the inland regions as opposed to the coastal regions.

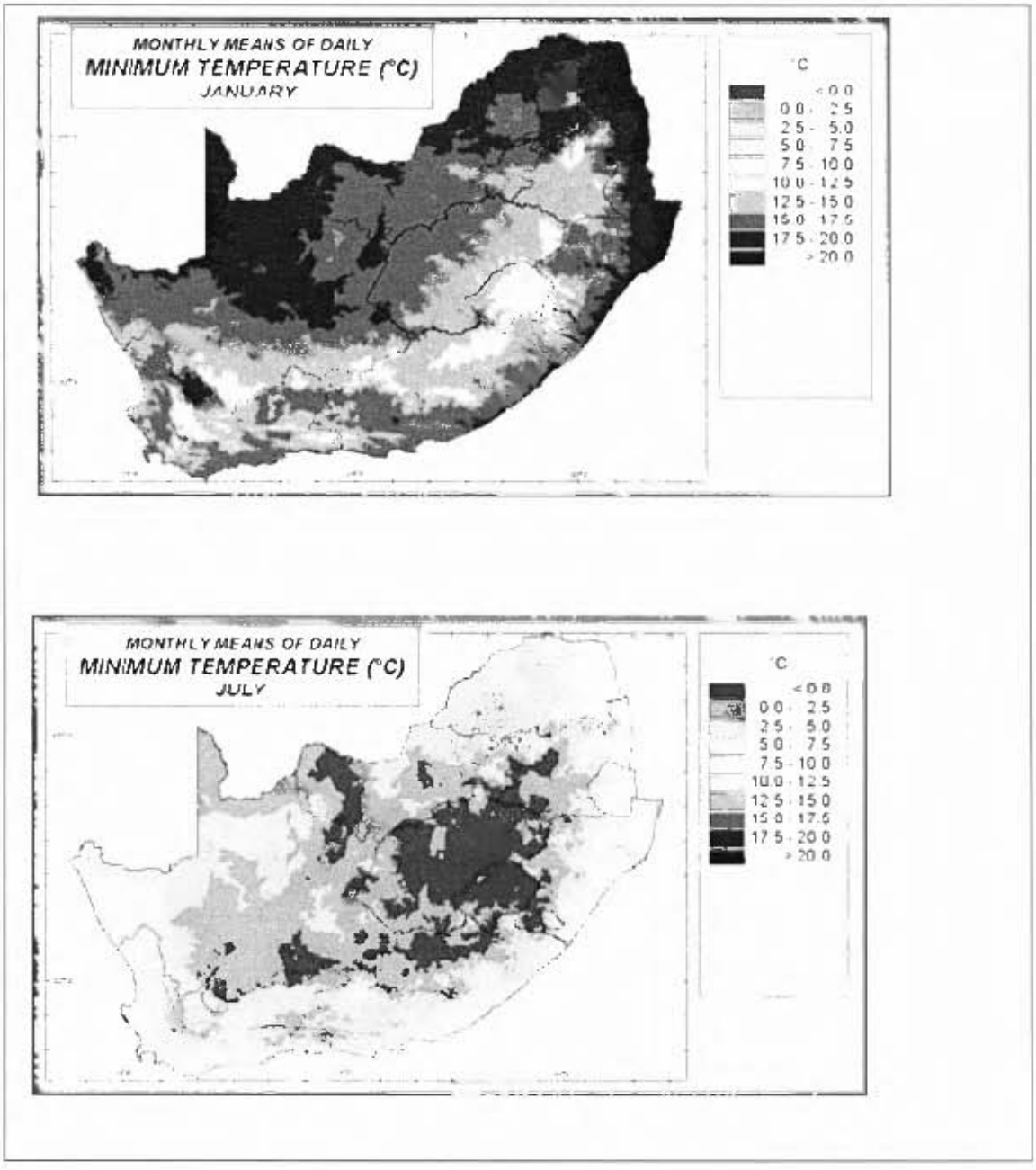


Fig 3.4 Mean temperature minima for January and July for South Africa (Schulze, 1996)

3.1.3 Vegetation

The Cape Floristic Region or Cape Floral kingdom (Cox, 2001) is made up of a number of different vegetation groups (see fig 3.5), of which the Fynbos biome, itself consisting of Fynbos and renosterveld, contributes the vast majority of the species richness associated with the region.

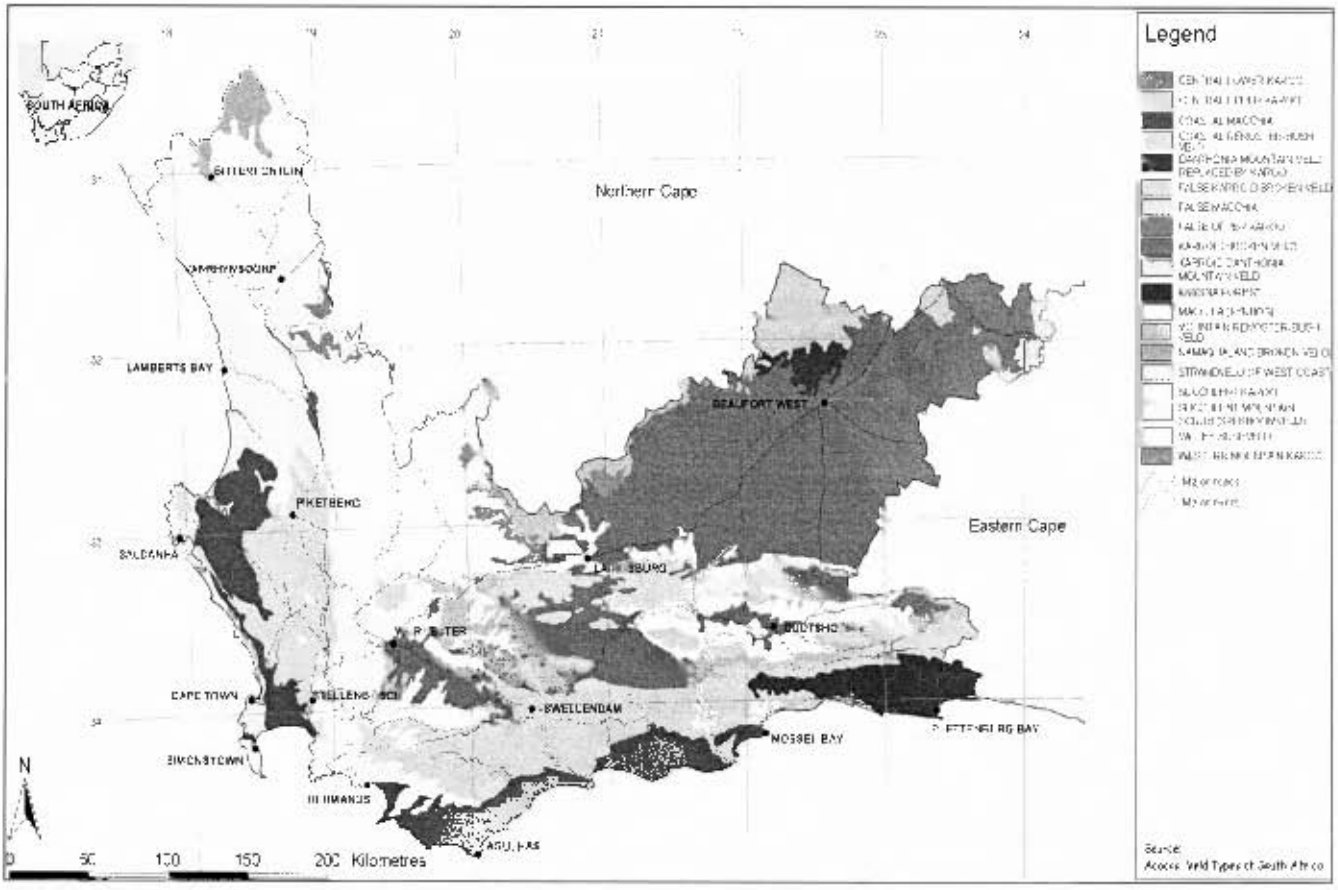


Fig 3.5 Vegetation distribution in the Western Cape (Acocks, Veld types of South Africa, 1988)

Included in this region are also species contributions from other vegetation types such as Afromontane forest, strandveld, and the Nama and Succulent Karoo (Cowling and Holmes, 1992; Cowling *et al.*, 1995). The Cape Floral Kingdom is the smallest of the six floral kingdoms described world wide, and is the only one contained entirely within the

borders of a single country. The high species richness, 8700 species, and high degree of endemism, approximately 68% make this region one of the most species rich on the planet (Rebelo, 1996) within a limited geographical area. Various fynbos vegetation types make up the bulk of the Fynbos biome, and this fynbos vegetation is characterized by the presence of three distinct elements:

- A restioid component consisting of members of the Restionaceae or Cape Reed family, which have been described as "shrubby grasses" and which replace grasses on nutrient poor soils where annual rainfall is made up largely of a winter component (Rebelo, 1996).
- An ericoid or heath component. This heath component consists of plants with reduced sclerophyllous leaves. Although the family Ericaceae features prominently in this component, many other families including the Asteraceae, Bruniaceae, Fabaceae, Rhamnaceae and Thymeliaceae are structurally similar and are also feature quite strongly
- A proteoid component consisting almost entirely of members of the family Proteaceae. These plants are generally broad leaved and form the over storey in the fynbos (Campbell, 1985; Moll *et al.*, 1984; Rebelo, 1996)

Seven endemic, or near endemic families also assist in characterising the fynbos. They include the Bruniaceae, Geissolomaceae, Grubbiaceae, Penaeaceae, Retziaceae and Stilbaceae. Fynbos is generally found on well leached nutrient poor soils consistent with soils produced through the weathering of the Cape Supergroup sandstones. Although in high rainfall conditions with sufficient nutrient leaching, fynbos may also be found on

soils derived from granite and shale, replacing Renosterveld. At low rainfall, for example to the north and east of this region, fynbos is usually replaced by Succulent Karoo vegetation. Various classification systems for fynbos have been devised, based on substrate, rainfall and altitude, and the effect that these factors have on the species composition of the fynbos types. Low and Rebelo, (1996) have described the fynbos under the following categories:

- Mountain Fynbos, the most widespread of the fynbos types, occurs along the Cape Fold Belt from Niewoudville to Cape Town, and from Cape Agulhas to near Port Elizabeth. It encompasses an area with large rainfall variations from 200mm to over 2000mm and is generally found on sandstone derived soils.
- Sand Plain Fynbos, found from the Olifants River mouth to Muizenberg at an altitude of 5m to 300m above mean sea level. Found in a region with rainfall varying from 200mm to 500mm per year, it is restricted to deep acid sands primarily of Tertiary origin.
- Grassy Fynbos found mostly in the Eastern Cape where the summer component of the yearly rainfall increases. Soils associated with this type of fynbos are generally finer grained sands derived from the Cape Supergroup, as well as quartzites and conglomerates of the Witteberg and Uitenhage Groups.
- Laterite Fynbos occurring on the Elim Flats in the Western Cape at an altitude of 15m to 100m above mean sea level. This fynbos type is found in a region of fairly uniform rainfall of between 440mm and 460mm per

year, and on soils associated with depositional landscapes, such as gravels, laterites and seasonally waterlogged soils.

- Limestone Fynbos found in the Western Cape between Walker and Moslem Bays at an altitude of 0m to 290m above mean sea level. This fynbos type is associated with winter and spring-autumn rainfall regions with rainfall varying from 350mm to 600mm per year. This fynbos type is restricted to calcareous, shallow sands overlying limestone and calcrete of the Bredasdorp Formation.

Also found within the Fynbos Biome along with fynbos are the following vegetation types:

- Renosterveld is characterized by the dominance of the family Asteraceae in particular, a single species Renosterbos *Elytropappus rhinocerotis.* Although this species is dominant, members of other plant families are also represented, such as the Fabaceae, Sterculiaceae, Rubiaceae and Thymeliaceae, all of which are characterized by reduced, tough, grey foliage. Typical Fynbos vegetation such as Ericaceae, Proteaceae and Restionaceae tend to be absent or found in very low abundance in Renosterveld. Renosterveld is also typified by high species richness of geophytic plants represented by the Iridaceae, Liliaceae and Orchidaceae. Renosterveld tends to occur where rainfall is between 250mm and 600mm, and where at least 30% of this rainfall occurs in winter. Renosterveld is largely found on fine grained soils, clays and silts derived from shales of the Malmesbury and Bokkeveld Groups (Moll *et al.*, 1984; Rebelo, 1996).

As this soil tends to be fertile, large areas of Renosterveld have been removed to make way for agriculture, predominantly wheat (Meadows, 2003).

- Afromontane Forest found within the Cape Floral Kingdom occur all along the mountain chains, where they are restricted to south facing ridges and ravines, where moisture is increased and the maximum effect of south westerly and south easterly driven rains is felt. Rainfall is generally greater than 700mm and can exceed 2000mm in some regions. Soils associated with Afromontane forest are generally well developed, but may be relatively shallow on steeper slopes. Vegetation may include various canopy forming trees, such as *Podocarpus* sp., *Curtisia dentata, Halleria lucida, Rhus* sp., *Ocotea bullata, Kiggelaria africana* to name a few. Various shrubs, herbs and ferns form an under storey, while trees such as Cape Beech *Rapanea melanophloeos* are abundant along the edges of the forest (Rebelo, 1996; White, 1993). Although water is a limiting factor to the spread of Afromontane forest, it is also thought that fire also plays a role in restricting further spread into fynbos and grassland areas (Luger and Moll, 1993).

On the margins of the Fynbos Biome, where winter rainfall is less pronounced, and where the rainfall is 200mm or less per year, various species associated with the Succulent Karoo may appear in conjunction with various fynbos species. Some of

these species are from the families Mesembryanthemaceae, Crassulaceae, Chenopodiaceae and also an increase in the Asteraceae.

3.1.4 Fire

As in southwestern Australia, fire has been an integral part of the environment in the Western Cape for a very long time, with a number of plant species developing fire adapted features such as fire triggered seed dispersal, fire triggered flowering and smoke triggered germination (Zedler, 1993). Fire plays an important role in plant distribution in the region, with diversity increasing in many areas post fire. Although it is not entirely clear as to what effect hunter-gatherer cultures used fires in the region, there has been much alteration of the natural fire regimes in the region following the arrival of pastoralist cultures and with colonial settlement in the region, and particularly more recently with the introduction of alien species into the environment. These alien species increase the fuel loading in the environment, meaning that when they do occur, fires tend to burn hotter, and for longer than they ordinarily would, leading to the destruction of a number of plants which would ordinarily survive natural fires and also the destruction of seed banks normally protected by soils (Clark, 1995; Cowling, 1992).

It is clear that the vegetation distribution patterns observed in the Western Cape today are the culmination of many years of interaction between large numbers of environmental variables. Climatic variables such as seasonality and reliability of rainfall and seasonal temperature variation, along with proximity to the coast have affected plant distribution,

as have the geological effects of soil nutrient status and the effects of fire. Relief and associated altitude changes and the effects that relief has on rainfall distribution plays an important part in microclimate variability and the creation of ecological niches, lending increased complexity to the already complex vegetation distribution patterns observed in the region.

3.2 Southwestern Australia:

This section describes the area which occupies the southernmost corner of the State of Western Australia. For the purposes of this study, the area is also defined as that area which falls within the mediterranean- climate, winter rainfall area. This region is bounded to the north and the east by arid regions and to the west and the south by the Indian Ocean and Southern Ocean respectively (Beard, 2000). Due to its comparatively high rainfall when compared to the regions to the north and east, it is sometimes defined as the area lying to the South West of the 300mm isohyet (Hopper, 1979).

3.2.1 Geology

The bedrock geological features in southwestern Australia are old, and these bedrock features are relevant in the fact that they are the source for the different substrates on which the vegetation is found growing today. The underlying geology of the region therefore has a part to play in the distribution pattern of vegetation found in the region

today. The geology of southwestern Australia is well documented, and a number of geological features constitute the region (see fig 3.6). Two features in particular make up the majority of the area under investigation, namely the Perth Basin and the Yilgarn Craton (Kendrick *et al.*, 1991b). The Yilgarn Craton is a feature which constitutes the bulk of the West Australian land mass. It is composed primarily of 2.8 million year old granites and greenstone belts. The craton appears to have been assembled between 2.94 and 2.63 Ga. by the accretion of formerly present blocks or terraces of existing continental crust (Barley and Groves, 1990; Wilde, 1999). The Craton is bounded on the west by the Darling Scarp and darling fault, which separate the Yilgarn Craton from the Perth Basin.

The Perth Basin is a thick sedimentary basin formed offshore of the Yilgarn Craton in several stages beginning in the late Permian. The Perth Basin began forming during the breakup of Gondwana as the Australian continental mass began rifting away from the African and Indian Land masses. During the Permian, the Perth Basin was marginal to a rift basin, resulting in the deposition of marine sediments which filled in areas of the basin. This infilling continued until the Jurassic. More recently, sedimentation in the Perth Basin has been Characterised by sand dune systems, biogenic limestones, sandstones and some shales all being deposited during the last 20 million years (Kendrick *et al.*, 1991a; Wilde, 1999) (see fig 3.7).

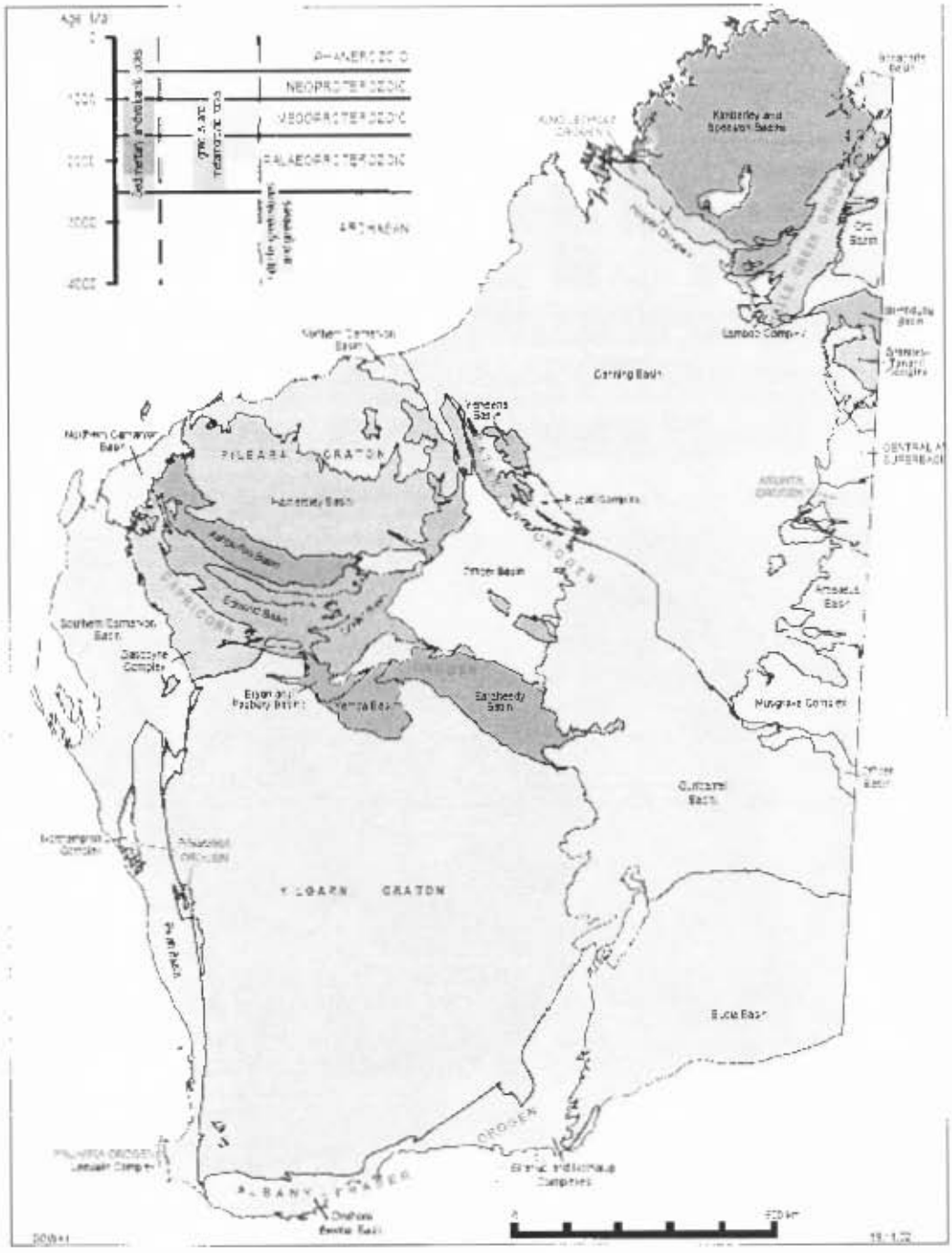


Fig.3.6 Underlying Geology of Western Australia, Courtesy of the Western Australian Geological Survey.

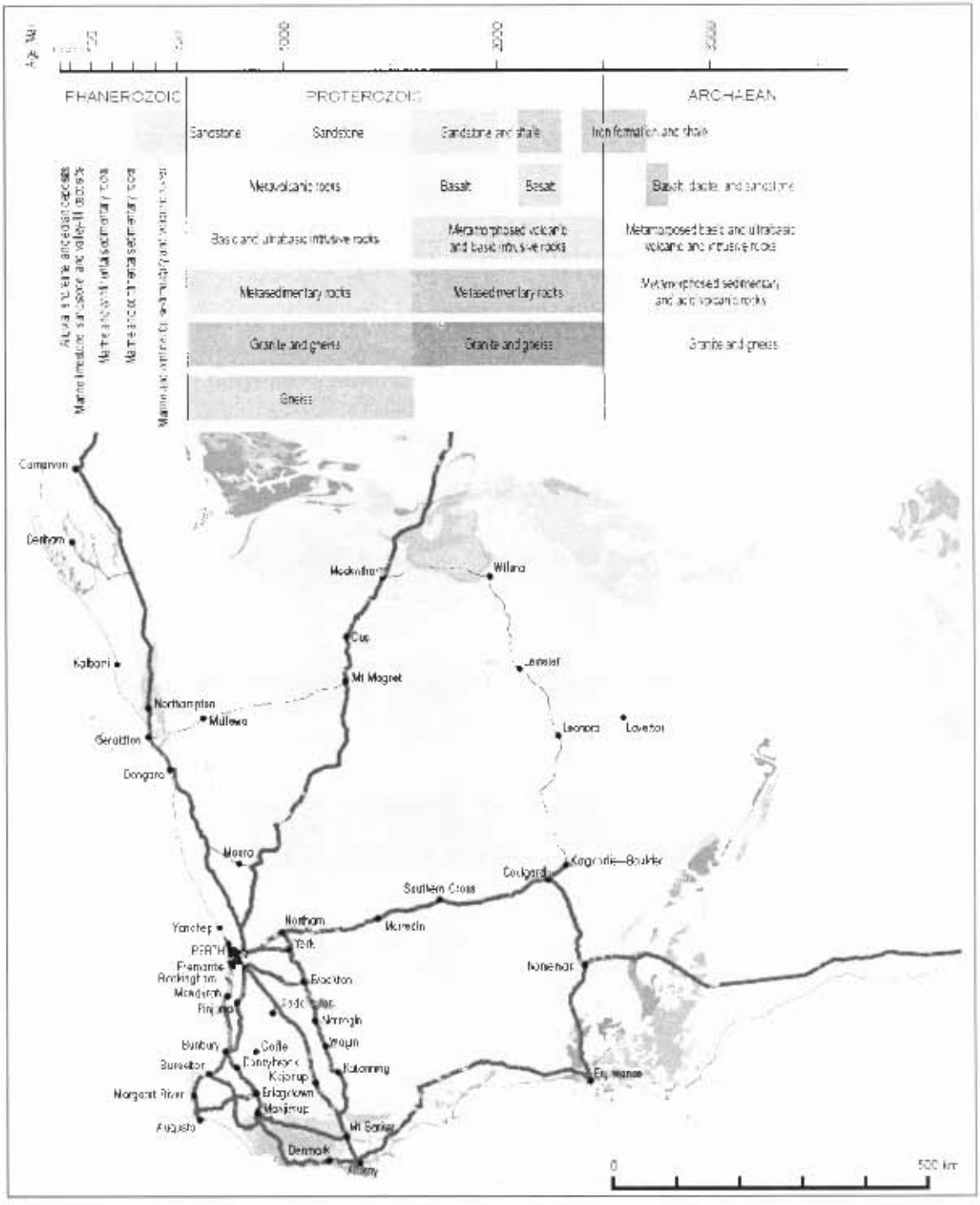


Fig 3.7 Detailed Geology of Western Australia. Courtesy of Western Australian Geological Survey.

These various geological features contribute to the relief of the region, and although with the exception of the Stirling Ranges, there are no substantial mountain ranges in southwestern Australia. This relief has some bearing on the vegetation distribution in the region. These changes in relief have an effect on local climatic conditions, creating a wider variety of environmental niches favouring various vegetation groups.

The local geology at each of the study sites is discussed later in this chapter. The soils found in southwestern Australia are generally poor in nutrient status and with the exception of the deep sand profiles found along the coastal plain, are fairly thin and poorly structured (Conacher, 1998). The coastal plain consists of primarily siliceous, deep sand profiles, but along the coast of the Leeuwin- Naturaliste region, some calcareous deep sand profiles can be found. The majority of the remainder of southwestern Australia consists of gravelly soils (gravel in a sand or loam matrix) and sandy duplex soils, some of which have sand overlying non alkaline clays, or a matrix of alkaline and non alkaline soils (Gov. of Western Australia, Department of Agriculture, 2002). Shallow water tables are also evident in areas of southwestern Australia, with areas of saline, wet soils have a marked effect on plant distribution.

3.2.2 Regional Climate

Southwestern Australia experiences highly seasonal climate patterns, with cool, wet winters during which rainfall is generally annually reliable, and warm, dry summers (see figs. 3.8 and 3.9). This particular pattern of seasonal temperature and rainfall variability accords well with the climatic parameters of a mediterranean-type climate. Summer arid

conditions are brought about by anticyclonic conditions with warm dry air brought from inland on a north easterly wind (Conacher, 1998; Semeniuk, 1986).

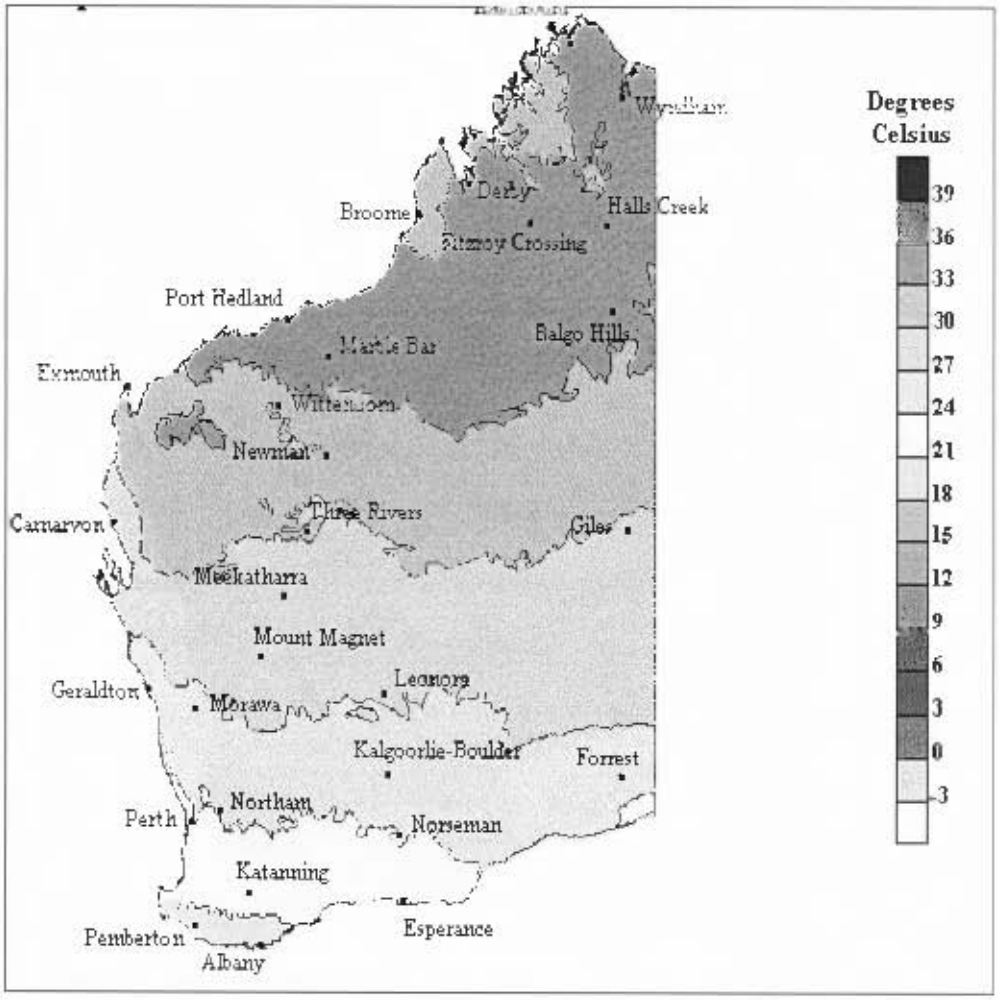


Fig 3.8 Average maximum annual temperatures for Western Australia. (Australian Bureau of Meteorology)

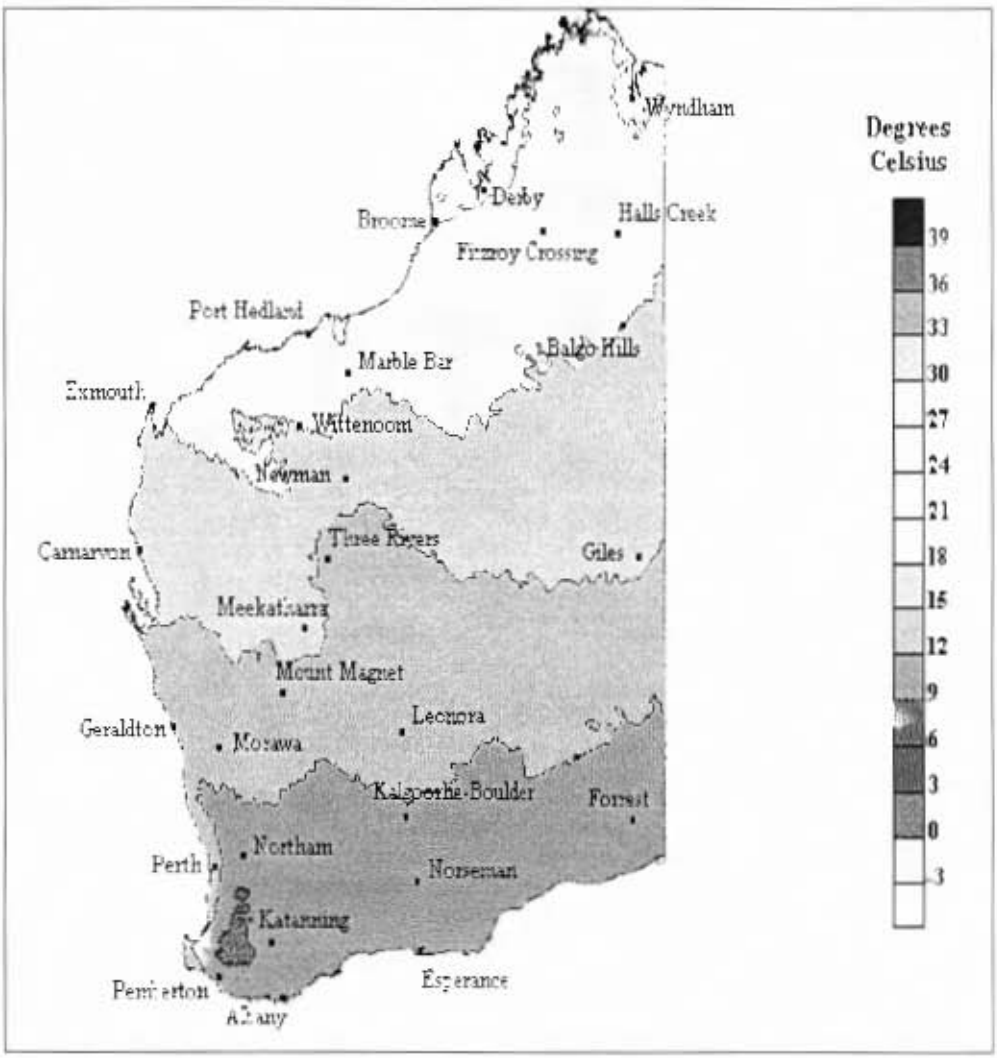


Fig 3.9 Average minimum annual temperatures for Western Australia. (Australian Bureau of Meteorology)

This situation changes during the winter months with rainfall in the region mostly associated with frontal activity due to mid latitude cyclonic development brought by the westerly wind belt (Shulmeister *et al.*, 2004). The effects of this frontal activity are felt more strongly in the southwestern coastal regions with rainfall reaching an annual average in excess of 1000mm and decreasing inland to the north east to less than 300mm

per annum near Southern Cross (Beard, 1990)(see fig 3.10). The topography of the southwestern Australian region is generally subtle. however, elevated features

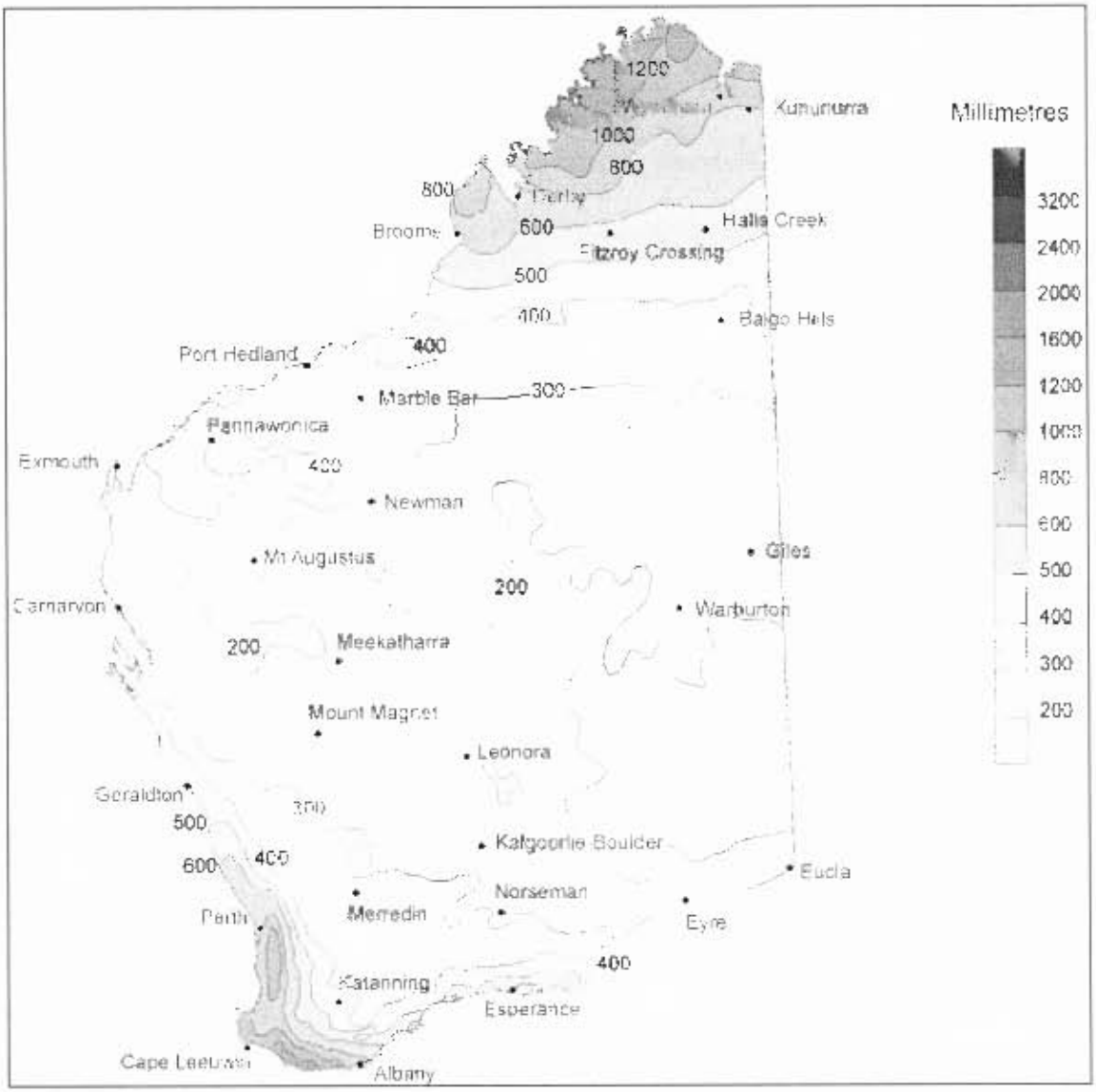


Fig 3.10 Annual average rainfall distribution for Western Australia (Australian Bureau of Meteorology)

such as the Darling scarp. Stirling Ranges and Leeuwin-Naturaliste ridge may lead to the occurrence of local orographic precipitation where moisture laden air is forced to rise over these landscape features (Conacher, 1998). This may lead to changes in vegetation

distribution, with areas of increased local precipitation favouring vegetation with higher rainfall dependence.

Temperatures in the region also vary greatly with latitude and proximity to the coast. Temperatures in the far south-west in close proximity to the coast tend to be milder with maximum temperatures very rarely exceeding 35 degrees Celsius in the summer and also rarely drop below 0 degrees Celsius in the winter. As one moves further inland however, particularly those areas east of the Darling plateau, temperature exceed 40 degrees Celsius in the summer months, and drop below 0 degrees Celsius at night in the winter months leading to frost formation. Table 3.2 lists comparative temperature and rainfall data from three sites within the region. The First, Mt Barker is the most easterly of the three sites and lies inland, while the remaining two sites lie on the coast to the west. Cape Leeuwin lies to the south of Cape Naturaliste and located in the far south west of the region.

Table 3.2 Climate data for selected sites in southwestern Australia (Australian Bureau of Meteorology)

Site	**Ave. Temp. January Deg. C.**		**Ave. Temp July Deg. C.**		**Ave. Rainfall mm**	
	max	min	max	min	Jan	July
Mt Barker	26.1	12.8	14.3	6.0	23.2	104.7
C.Naturaliste	25.3	15.2	16.3	10.4	10.5	163.3
C.Leeuwin	23.0	16.9	16.3	11.3	16.2	183.0

From this data it can be observed that the temperatures experienced at the coastal sites exhibit a smaller range than those experienced inland. The temperatures are also more moderate than those experienced by the inland site. This can be attributed to the

proximity of the ocean which acts to moderate the temperatures experienced at these coastal sites. From the rainfall data it can be observed that there is greater seasonal rainfall variability experienced at the western coastal sites in comparison to the inland site further to the east at Mt Barker. It can also be observed that there is a general increase in rainfall as one moves westward from Mt Barker and a further increase if one moves south west to Cape Leeuwin. The highest rainfall in the region would appear to be encountered in the far southwestern areas of the region. These variations in rainfall, temperature and seasonality have a very marked effect on the vegetation distribution throughout the region, which is further complicated by issues such as microclimate.

3.2.3 Vegetation

Southwestern Australian vegetation has historically been the subject of much research, particularly with reference to biodiversity (Beard, 1969; Diels, 1906; Gardner, 1942). Although the vegetation distribution across the region is not completely uniform (see fig 3.11), the forests, woodlands, shrublands and heath of southwestern Australia collectively exhibit an extraordinary species richness and high degree of endemism (over 70%), leading to this region being referred to as a biodiversity hotspot (Myers *et al.*,2001). Although this region generally has a very subdued topography, the effect of this topography on rainfall distribution and subsequent water redistribution is widely regarded as a vital contributing factor to the determination of vegetation distribution in the region (Beard, 1990). Although the region as a whole exhibits high species diversity, there are a few smaller regions where species diversity is especially elevated. These smaller regions

tend to be characterized by relief more prominent than the surrounding regions. This relief provides a larger range of habitats and soil varieties, which are thought to be responsible for the increased biodiversity. These regions, such as the Stirling Ranges, Mount Lesueur and Fitzgerald river region contain some 30% of the species found within the Southwest Botanical region, in only 2% of its surface area (Lamont, 1984). Most of the native plants in the region are adapted well to the nutrient poor sandy or lateritic soils. Due to the stable nature of the geology of the region, many varied soils have developed locally, along with local vegetation, another factor that may have contributed to the complex vegetation distribution patterns that are evident. Although changes in the vegetation patterns of the southwestern Australian region are generally very subtle, they are at the same time very complex, and a number of general classifications can be made with regards to dominant vegetation. The boundaries of these classified regions are by no means strictly defined, and areas exhibiting species from more than one of these classified regions is common. The major vegetation formations found in southwestern Australia were mapped and classified according to the dominant plant types, their height and spacing, and then the species composition (Beard, 1979; Itzstein-Davey, 2003).

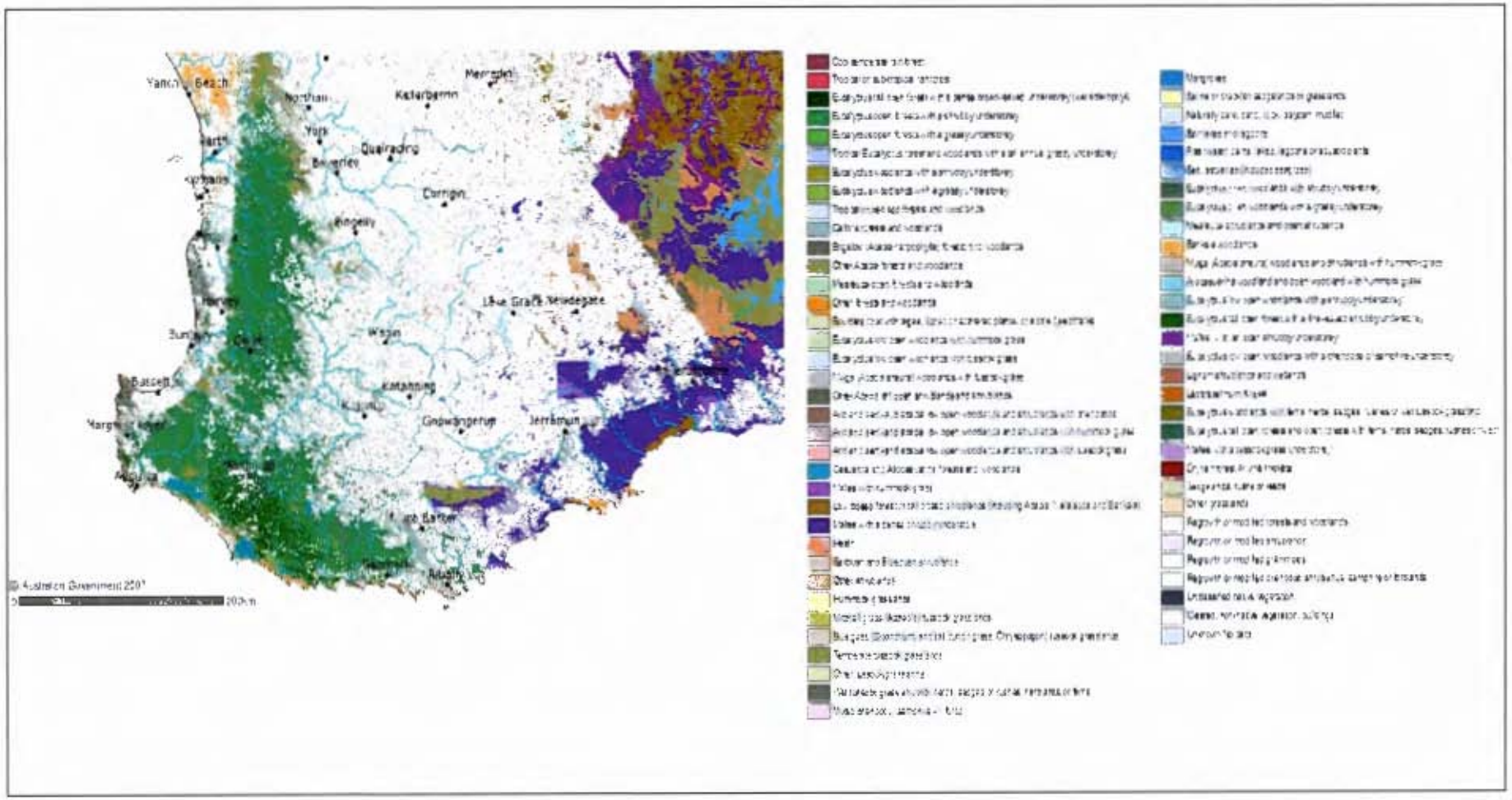


Fig 3.11 Vegetation distribution patterns in south western Australia (Australian government, C.A.L.M)

Five botanical districts were identified, of which some of them were then further divided into sub districts. The districts that were identified as follows:

- Darling Botanical District (southwest forest region) containing the:

    - Drummond Botanical Subdistrict (Swan Coastal Plain): consisting of *Banksia* low woodland on leached sands with Melaleuca swamps. Tuart (*E. gomphocephala),* jarrah (*E.marginata)* and marri (*Corymbia calophylla)* on less leached soils. Winter precipitation is between 300 and 500 mm per year. This vegetation type is found on low lying plains with recent sands.

    - Dale Subdistrict consisting of jarrah forest on ironstone gravels, with marri-wandoo forest on loamy soils with a sclerophyll under storey. Winter precipitation is 600-1200mm per year and this vegetation type is found on the duricrusted plateau of the Yilgarn block, with ironstone gravels and loamy soils.
    - Menzies Subdistrict consisting of forests similar to Dale Subdistrict, but with an under storey similar to the Warren Subdistrict. Winter rainfall is 600 -1200mm per year and this vegetation type is found on the duricrusted plateau of the Yilgarn block, with ironstone gravels and loamy soils.

- Warren Subdistrict consisting of tall Kari forests on deep loams and jarrah-mari forests on leached sands. Extensive paperbark and sedge swamps are found in the valleys. Rainfall is greater than 1000mm per year. Predominantly found on Archaean granites.

- Irwin Botanical District (northern sandplains region) consisting of scrub-heath on the sandplains near the coast and *Acacia-Casuarina* thickets further inland. *Acacia* scrub and scattered *E.loxophleba* are found on hard setting loamy soils. Winter precipitation is between 300mm and 500 mm per annum, with this vegetation type found in the sedimentary basins within the Perth Basin.

- Avon Botanical District (wheat belt region) consisting of scrub-heath on the sandplains, with *Acacia-Casuarina* thickets on ironstone gravels and woodlands of *Eucalyptus loxophleba*, *Eucalyptus salmonophloia* and wandoo on loams, halophytes and saline soils. Winter precipitation is 300mm – 650mm per annum. This vegetation type is found on the undulating plateau found on the Yilgarn Block.

- Roe Botanical District (mallee region) consisting of a general cover of mallee with *E.eremophila* patches of eucalypt wood land are found on lower ground with scrub-heath and *Casuarina* thickets on residual plateau soils. Winter rainfall is 300mm-500mm per annum, and this vegetation type is found on Archaean and Proterozoic granites, overlain by Tertiary sediments.

- Eyre Botanical District (Esperance plains region) consisting of scrub-heath and mallee-heath on sandplains, with *E.tetragona.* Mallee occupies the valleys. Winter rainfall is 500mm -700mm per annum, with this vegetation type mainly found on Eocene sediments with granite and quartzite outcrops (Beard, 1979; Beard, 1981)

3.2.4 Fire

Fire has been a part of the landscape in Western Australia for millions of years, with charcoal records older than 3 million years being dated at Yallalie, an in-filled meteor impact crater in the region (Atahan *et al.*, 2004). This evidence is proof that the region has had a natural fire regime for a very long time, which has in the more recent past been modified through human interaction with the environment. Further evidence that fire has been a part of the landscape for an extended period of time is the fact that a number of plants in the region have developed adaptations to fire, such as fire induced flowering or smoke induced germination (Hopper, 2003). Further adaptations to fire survival include resprouting, whereby the plant regenerates from protected below ground organs following a fire. Research has also shown that fire may affect below ground seed banks, leading to an increase in initial plant growth in plants germinated from seeds which had been heated (Hanley, 2001).

The fire regime was first altered through aboriginal tribes in the region using fire as a tool for hunting and land management in order to ensure food supplies (Mulvaney and Kamminga, 1999). It can be said with certainty that the fire frequency, intensity and seasonality was altered with the arrival of aboriginal man in these regions (Adamson and

Fox, 1982). What effect these alterations had on vegetation distribution in the region is still a matter of much debate, but it is thought that the human – environment interaction in terms of fire regimes may have reached some sort of equilibrium and that the environment as first witnessed by European settlers may have been quite different to the environment pre dating aboriginal settlement. The post colonial fire regime is also much altered, with large areas cleared for agriculture. More recent forest management in the region has tended toward a reduced fire frequency which may also have an effect on species diversity as old growth communities exhibit a lower number of species when compared to post fire communities (Yates *et al.*, 2002).

In summary, it is clear that the complex vegetation distribution patterns observed in southwestern Australia are as a result of the long term interaction of a number of variables related to climate, microclimate, geology, geomorphology, continentality, fire and human influence. Each one of these factors has contributed to the evolution of the present day flora, and any future modification of these factors will lead to alteration in the spatial distribution of the flora as it observed in southwestern Australia today.

3.3 Local Setting: Western Cape:

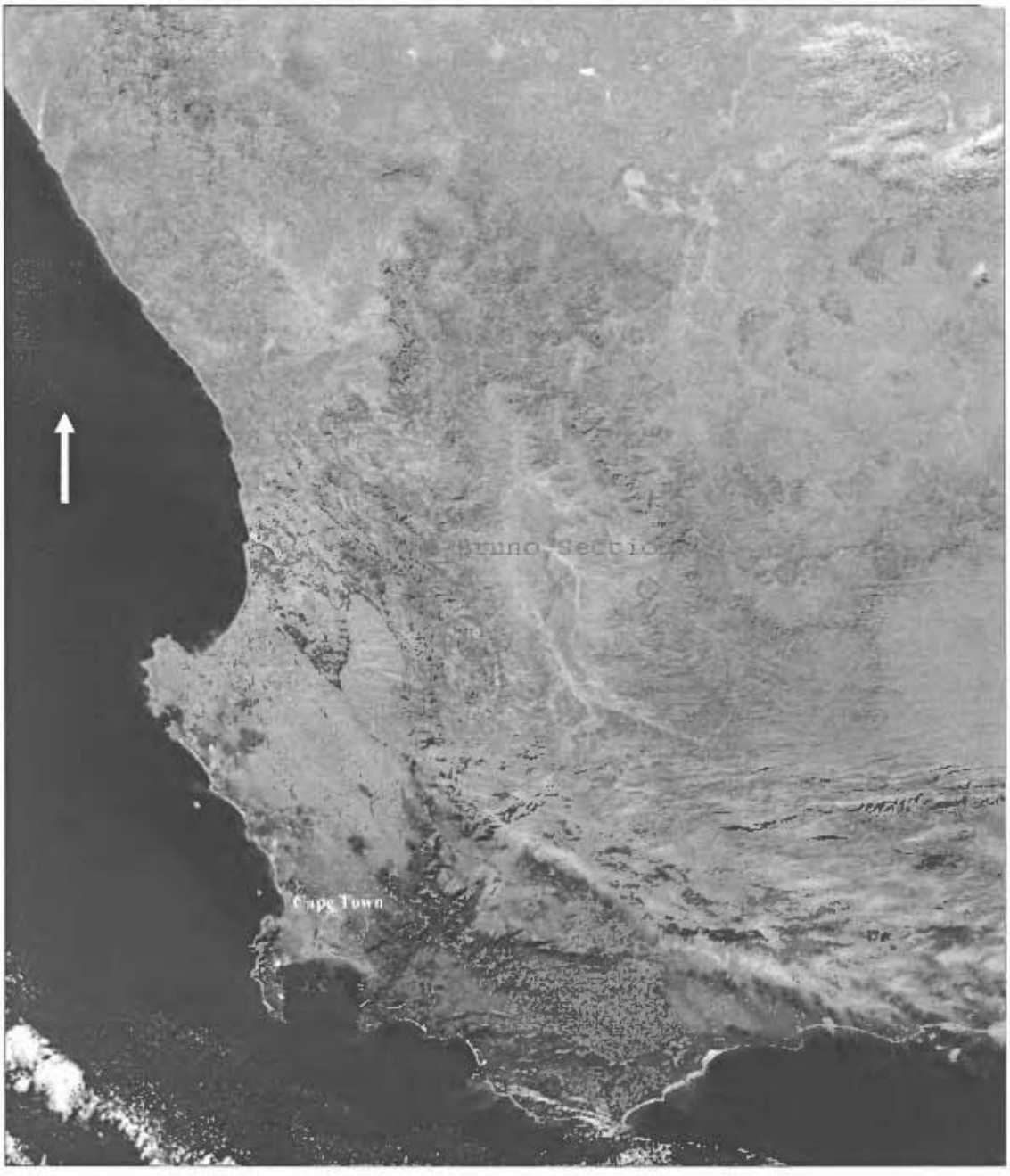


Fig 3.12 Location of study sites in the Western Cape, South Africa

3.3.1 Bruno section:

3.3.1.1 Description of site

32 Deg 08,265 S 19 Deg 03,318 E

The Bruno section is a 10m exposure through the alluvial and colluvial sediments in the river bed of the head waters of the Sand River (see GPS location, fig 3.12, and plate 3.1).

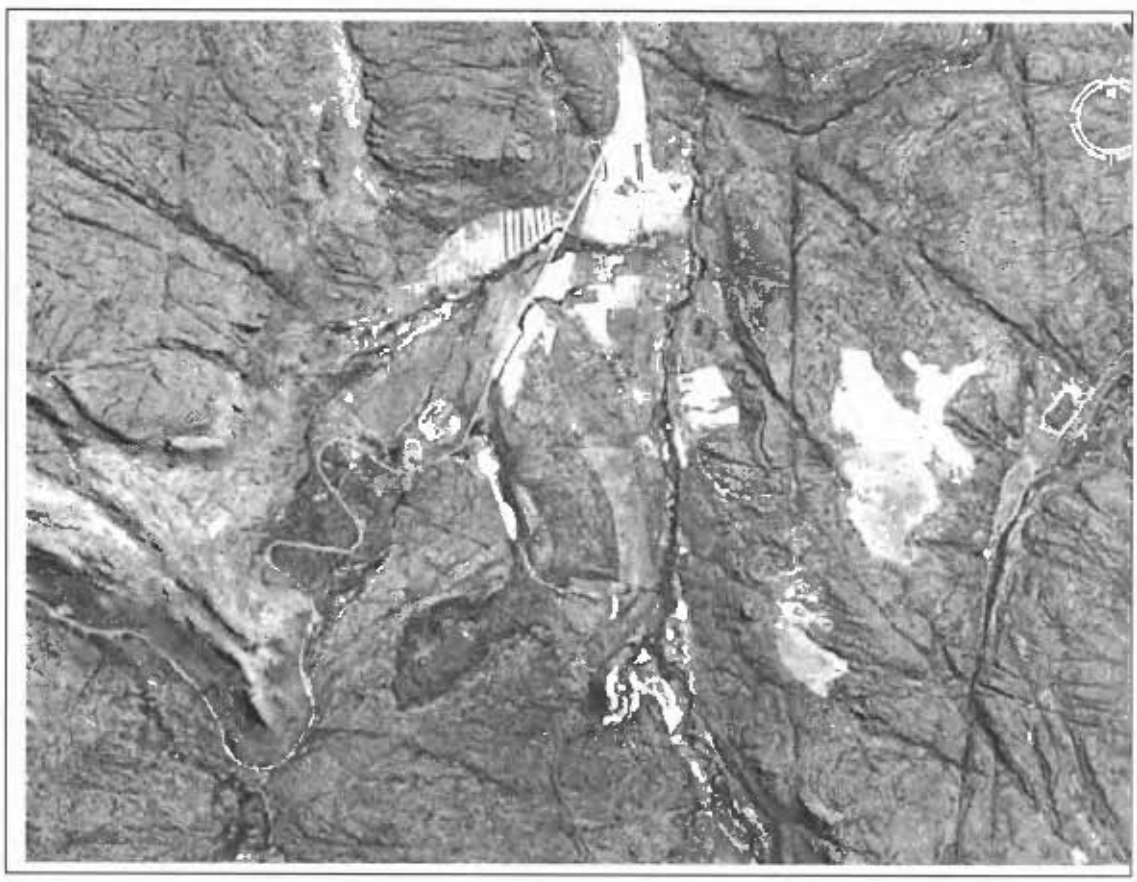


Fig 3.13 Satellite (Google Earth) image of Bruno Section and surrounds.

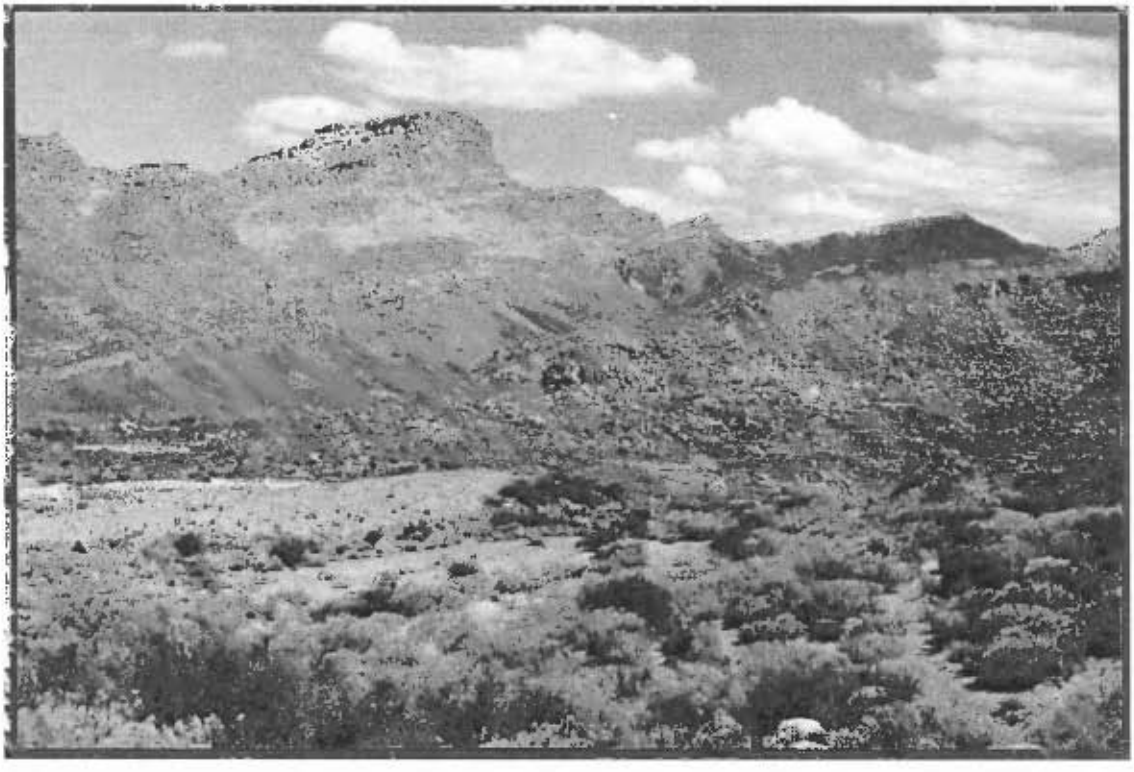


Plate 3.1 View of Sand River valley containing Bruno section.

This exposure is on the farm Klein Pakhuis found in the Pakhuis Pass region of the northern Cederberg. The site falls within a larger feature, namely the Pakhuis basin, which lies to the east of the North South aligned Pakhuisberge which form part of the Cederberg Range (Meadows and Holmes, 1999). The average altitude of the basin is 500m above sea level. The exposure has revealed a number of stratigraphic units, including aeolian, alluvial, and colluvial units, as well as various finely laminated clay and silt layers presumably of lacustrine origin as well as a massive organic unit at the base of the sampled sequence. The Sand River flows throughout the year, but flow rates are seasonal, with increased winter rainfall, flash floods and heightened river levels are responsible for the incision through the in-filled valley sediments forming the floor of the

pakhuis basin. This incision has lead to exposures of up to 18m in some parts of the basin. It is in these exposures that the complex stratigraphy of the region can be studied.

3.3.1.2 Local geology

The local Geology is dominated by the Table Mountain Sandstone group sediments and shales (Theron, 1983) of the surrounding mountains. These mountains almost completely enclose the Pakhuis basin area. The Sand River and a number of tributaries drain the basin through a narrow gorge known as Riethuis se Gang, which coincides with the base level of the basin. A knick point is found at the upstream end of the gorge, after which the land drops some 100m to a new base level on a structural platform (Meadows and Holmes, 1999). Thus it appears that the formation of the basin is both structurally and lithologically controlled.

3.3.1.3 Local Climate

The site falls within the WRZ, receiving approximately 200mm of rainfall annually. This would place the site in one of the drier areas of the Study region. The area has warm, dry summers with an average maximum temperature of 27 degrees C, and an average minimum summer temperature of 11 degrees C. Absolute maximum summer temperatures are known to exceed 40 degrees C. Winters are much cooler, with an average Maximum winter temperature of 13 degrees C and an average minimum winter temperature of 2 degreesC.

3.3.1.4 Local Vegetation

The Pakhuis pass region is at the northern limit of the Fynbos Biome, and as such exhibits a mix of fynbos species and Karroid species adapted to the more xeric conditions of the karoo. Scott (2007) describes the region as exhibiting Dry Mountain Fynbos as described by Low and Rebelo (1996). The area is also described as a transitional area, moving toward Lowland Succulent Karoo vegetation, exhibiting the presence of xeric plant taxa such as Aizoaceae, Crassulaceae and Mesembryanthemaceae. The pakhuis pass region is also one of the last remaining areas of Renosterbos typified by the species *Elytropappus rhinocerotis,* a member of the family Asteraceae. Renosterbos tends to grow on the more nutrient rich soils derived from shale weathering. Restioids such as *Ischyrolepis* spp. are present in the area as are a number of the Asteraceae and Chenopodiaceae. Various shrubs and tree species are represented by *Rhus, Diospyros, Euclea* and *Dodonea* spp., while protected thicket vegetation such as *Olea* and *Brabejum* may be found in rocky outcrops above the basin. Typical mountain fynbos families are found at higher altitude in the catchment area, and include members of the Proteaceae, Restionaceae, Ericaceae, Asteraceae and Fabaceae

3.3.1.5 Degree of Disturbance

The upper reaches of the Sand River catchment fall within a conservation area and as such are regarded as relatively pristine. As to what effect pre-colonial *Khoi San* and *Khoi*

Khoi people had on this region remains largely a matter of speculation. It is also possible that the fire regime in the region has been altered due to land management practices. The lower reaches of the river as well as the basin itself have been impacted quite deeply through agricultural practices with both the planting of crops and grazing of livestock leading to the removal of much of the native vegetation. The introduction of a number of alien species has also contributed to the impacts of human activities in the area. Removal of water from the rivers and streams for agriculture, have also lead to an altered flow regime in the region. The agricultural land on the farm Klein Pakhuis though, is being allowed to return to its natural state, which may take a considerable amount of time.

3.3.2 Lake Michelle, Noordhoek

3.3.2.1 Description of site

18 deg 23, 15 E 34 deg 07, 00 S

Lake Michelle is located in the Noordhoek valley on the Cape Peninsula in the Western Cape, South Africa (see GPS location and fig 3.14, 3.2). At present, Lake Michelle can be described as a severely impacted coastal wetland, although it was described in the 1960'

Fig 3.14 Satellite (Google Earth) image of Lake Michelle and surrounds.

as a seasonal salt pan, always dry in summer, but forming a shallow lake in the wet winter season (Winterbottom, 1960, in Glassner, 1999).

Plate 3.2 Coring the edge of Lake Michelle wetland.

Although the wetland is at present at the edge of a large housing development, it remained largely undisturbed with the lake acting as a sink for a large portion of storm water drawn from the Noordhoek valley. Outflow from the lake is through an artificial conduit at the northwest end of the lake (Akunji, 2005). Although there is seasonal

expansion and contraction of the lake according to seasonal rainfall patterns, the Lake remains a permanent, but shallow water body throughout the year.

3.3.2.2 Local Geology

The geology of the Noordhoek valley is dominated by the quartzitic sandstones of the Table Mountain Sandstone (TMS) group. These sandstones rest on a granitic base formed by the Cambrian Cape Granite (Akunji, 2005). The TMS comprises of two groups of sediments, the older Graafwater formation (characterized by laminated siltstones and thin fine grained mudstone) and the younger Peninsula Formation (characterized by horizontal Quartzarenite sequences) (Theron,1983). Weathering of these sedimentary groups has resulted in kaolin in the case of granite weathering, and acidic, low nutrient soils in the case of Peninsula Formation weathering. Inland of the Noordhoek basin, the area is dominated by coastal dunes which are underlain by peaty silica sand forming the Noordhoek Member of the Pleistocene Springfontein Formation (Reid *et al*, 1999 in Akunji, 2005) Toward the coast, the semi consolidated calcareous sand of the late Pleistocene Velddrif Formation and the Holocene, unconsolidated aeolian Witzand formation overlie the Springfontein formation (Reid *et al*, 1999 in Akunji, 2005). Modern Dunes located inland from the present shoreline were created during the Holocene transgression when sea level was +3m approximately 6000 years ago. The regression which followed resulted in the coastal zone prograding seaward again, leaving behind an extensive system of marshlands and water bodies (Rogers, pers com. Cited in Davies and Gassner, 1999)

3.3.2.3 Local Climate

The study site falls within the WRZ, with an approximate annual rainfall of 600mm. The surrounding mountain ranges, reaching an altitude of over 900m above sea level may experience annual rainfall in excess of 1000mm per annum. Summers are warm, with an average maximum temperature of approximately 26 degrees C. Winters are cooler, and wet, with an average minimum winter temperature of approximately 7 degrees C (Akunji, 2005).

3.3.2.4 Local Vegetation

The system is dominated by aquatic and wetland species such as pondweed (*Potamogeton pectinatus)* as well as *Phragmites australis.* Through human intervention and poor management, the surrounding area is impacted by alien invasive species, in particular the areas of dune thicket vegetation which have been almost entirely replaced by members of the Acacia Family i.e. Rooikraans (*Acacia cyclops).* Dune scrub communities are restricted to younger alkaline, shelly sands and are dominated by members of the Restionaceae and Proteaceae. Water feeding the wetland system has its source in the mountainous regions surrounding the site and flows through rather more pristine areas dominated by species rich Fynbos vegetation. This Fynbos vegetation is classified as typical Mountain Fynbos and is characterized in particular by the presence of a few important plant families, such as the Ericaceae, Proteaceae and the Restionaceae as well as a vast number of other herbaceous plant taxa (Cowling *et al.*, 1995). Sheltered

mountain kloofs and smaller valleys within the Noordhoek valley are also typified by well developed afromontane forest elements and closer to the coast, by some milkwood forest.

3.3.2.5 Degree of Disturbance

Continued human impacts through the construction of housing estates, small scale agriculture and small holdings have had a marked impact on the region as a whole. Although the area was identified and originally sampled before the construction of the housing project, the area is today heavily impacted on the Eastern side, with the Western margin being continuous wetland running to the beach and subsequently the ocean. Large areas of natural vegetation have been removed in order to facilitate this construction, thereby altering the flow regimes for the wetland and sedimentation rates. Pristine areas appear to be restricted to the surrounding mountainous regions which fall under Cape Nature protection. One of the most noticeable impacts in the area is the introduction of alien species, in particular members of the Australian *Acacia* genus, and in particular *Acacia cyclops.* The introduction of *Pinus* sp. to areas away from the site, as well as *Acacia* sp. have had a marked effect on water availability in the area, with this invasive vegetation using far more water than the indigenous vegetation (Akunji, 2005). With the continued population growth and continued development in the area, it is likely that the site will continue to be affected by human impact in the foreseeable future.

3.4 Local Setting: Southwestern Australia

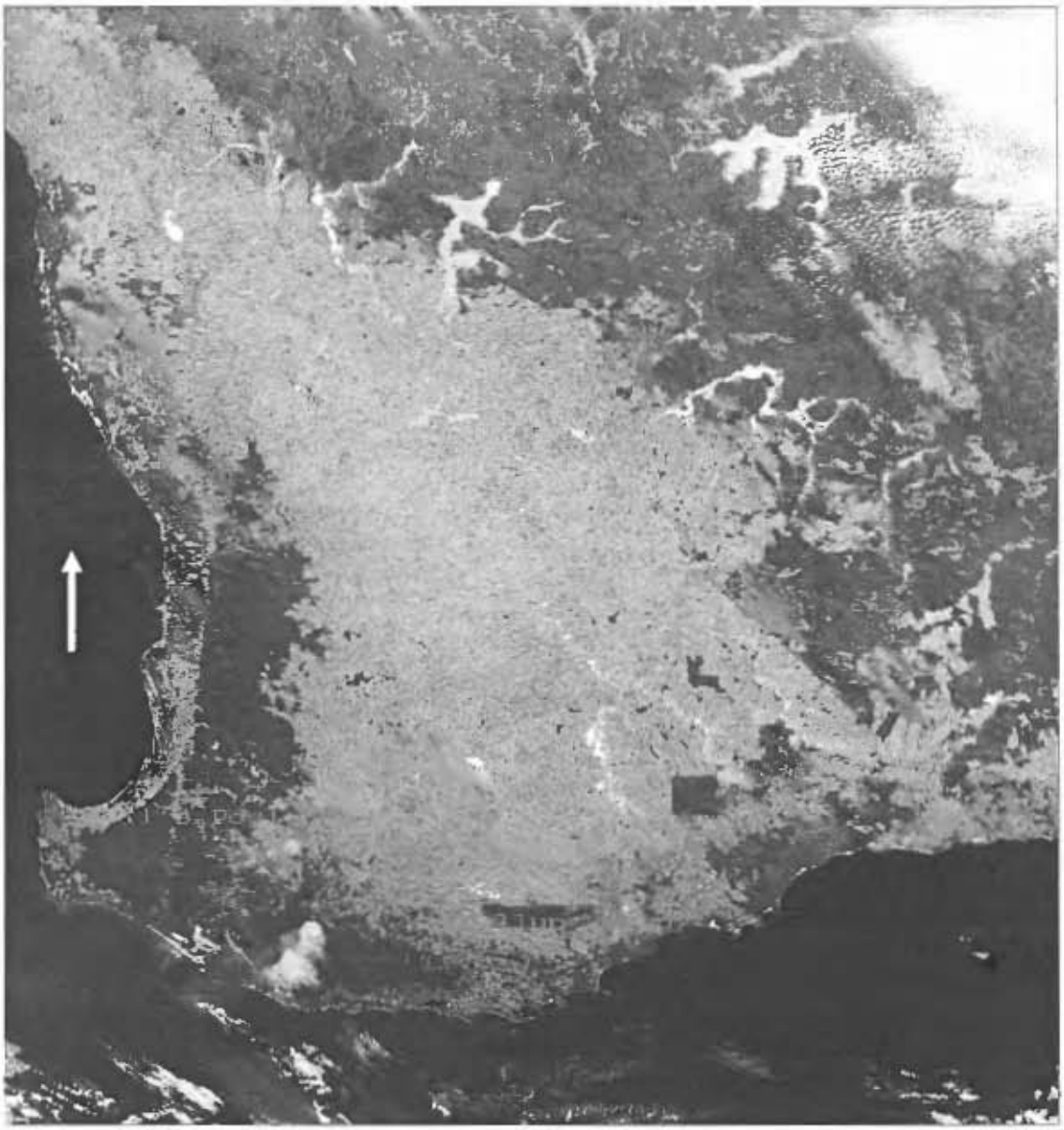


Fig 3.15 Location of Study sites in Southwestern Australia

3.4.1 Wambellup Swamp:

3.4.1.1 Description of site

34 deg 31. 20 S 117 deg 26. 30 E

Wambellup Swamp lies approximately 20km north west of the town of Mount Barker in Southwestern Australia (see GPS location). The swamp lies within a 470 ha nature reserve (see fig 3.16) at an altitude of approximately 235m. The swamp as it is called is

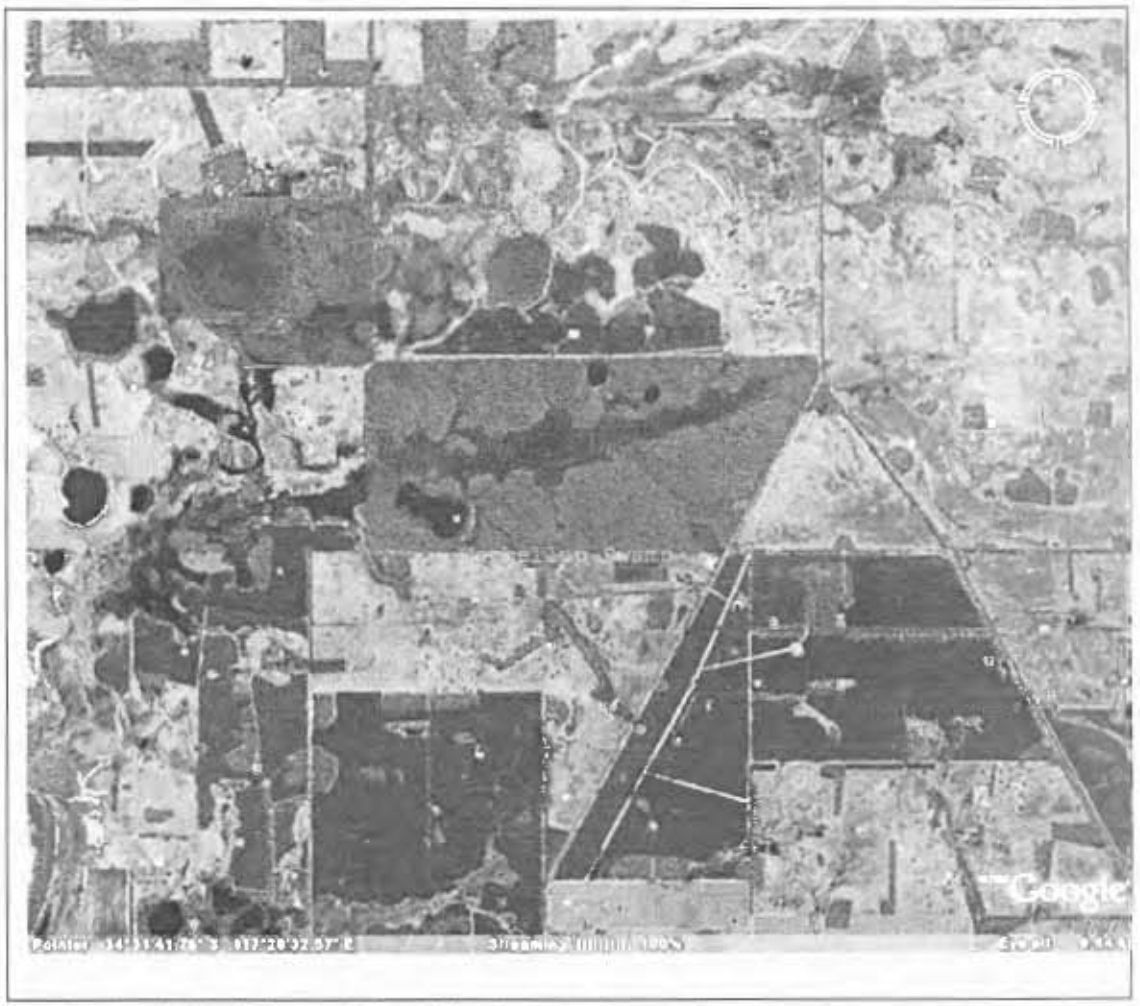


Fig 3.16 Satellite (Google Earth) image of Wambellup Swamp and surrounds.

one of a series of shallow lake systems that are scattered throughout the region. A number of these lakes are merely expressions of ground water levels, while others are linked to specific catchment areas.

Wambellup Swamp and the small conservation area surrounding it are administered by the Department of Conservation and Land Management (C.A.L.M.). Wambellup Swamp is situated in an area characterized by very gently sloping topography resulting in a shallow lake system (see plate 3.3). The persistence of lacustrine conditions is seasonal

Plate 3.3 Wambellup Swamp

with a summer drying period. Although there is a lack of standing water in the summer months, the system does not undergo complete desiccation, but is reduced to a large area of mud. According to a C.A.L.M. management report for wetlands in the region, water is persisting in the region for longer periods than previously due to clearing of vegetation in the catchment area, leading to increased runoff. This process is reversed in the wet winter season, where the system fills with water again, attracting large numbers of wading and aquatic birds. This seasonal fluctuation in water level could result in seasonal variations in siltation rates and formation of lacustrine sediments.

3.4.1.2 Local Geology

The surface sediments of the region are underlain by the Achaean granetoid bed rock features of the southern end of the Yilgarn Craton. The area is characterized by very low gradient and the dominant relief features are the Stirling Ranges found to the east. These ranges consist of quartzitic and metasediments (Wilde, 1999). Soils in the region consist mainly of a couple of metres of loamy sand and alluvium overlying 4 to 10 metres of Pallinup formation siltstones. This Pallinup formation has in many places been deeply weathered to form heavy silty clays which hinder water movement (Ferdowsian, 1997)

3.4.1.3 Local Climate

Wambellup Swamp falls within the winter rainfall zone, with the wettest months falling between April and August. The average annual rainfall in the area is approximately 560

mm per annum. Average maximum summer temperatures for the area are around 26 degrees C with an average minimum of 13 degrees C. Maximum and minimum average winter temperatures are 14 degrees C and 6 degrees C respectively.

3.4.1.4 Local Vegetation

The immediate region surrounding the Wambellup System falls within a conservation area and as such is presumed to contain natural vegetation communities and assemblages. The government management report for the region describes the reserve as substantially undisturbed. The entire margin of the wetland is typified by a dense stand of Swamp Paper Bark trees (*Melaleuca cuticularis).* The reserve beyond this dense stand of *Melaleuca* is described as a *Corymbia callophylla, Eucalyptus marginata* woodland over a dense understory consisting of a mix of many herbaceous taxa. A species list for the region supplied by the West Australian Herbarium indicates the presence of a number of heathland taxa in the vicinity. Various members of the Restionaceae are present, while the Proteaceae are represented by members of the *Hakea* and *Banksia* genera. The Epacridaceae are represented my by the genus *Leucopogon.* Chenopodiaceae are also present, perhaps hinting at seasonal salinity in the area, or perhaps the onset of secondary salinity through ground water input.

3.4.1.5 Degree of Disturbance

The immediate area surrounding Wambellup swamp falls within a conservation area, and as such remains largely undisturbed, however due to the limited size of the conservation area, disturbance to the land in the immediate surrounds has had an impact on the hydrology of the system, which in turn has affected the plant communities within the reserve. Agriculture and the clearing of natural bush in the catchment area have had an effect on drainage in the region. Where before, the wetland area was thought to be in equilibrium with the rainfall and flow regime of the catchment area, it is now believed that the increased runoff due to these agricultural practices has increased the seasonal residence time of water in the system. This increased residence time would favour different plant taxa at the site when compared to the normal flow regime (Ferdowsian, 1997). Perhaps the single largest concern for the wetland area is the issue of salinity, with many of the wetland system in the region exhibiting increased salinity due to alteration of the groundwater levels through the removal of trees by agriculture and regional development. This increase in salinity in the wetland system would greatly alter the taxonomic makeup of the surrounding vegetation, preventing a number of taxa present in the area today from growing, thereby reducing the biodiversity of this important conservation area.

3.4.2. Devil's Pool:

3.4.2.1 Description of site

34deg 00.757 S 115deg 01,021 E

Devil's Pool is a small lacustrine system near the terminal end of the Boodjidup brook drainage system (see GPS location and fig 3.17), located in the far southwestern corner of Western Australia. The system is situated a valley where the Boodjidup system has cut a path though the Leeuwin Naturaliste ridge. The study site is located within the Leeuwin –

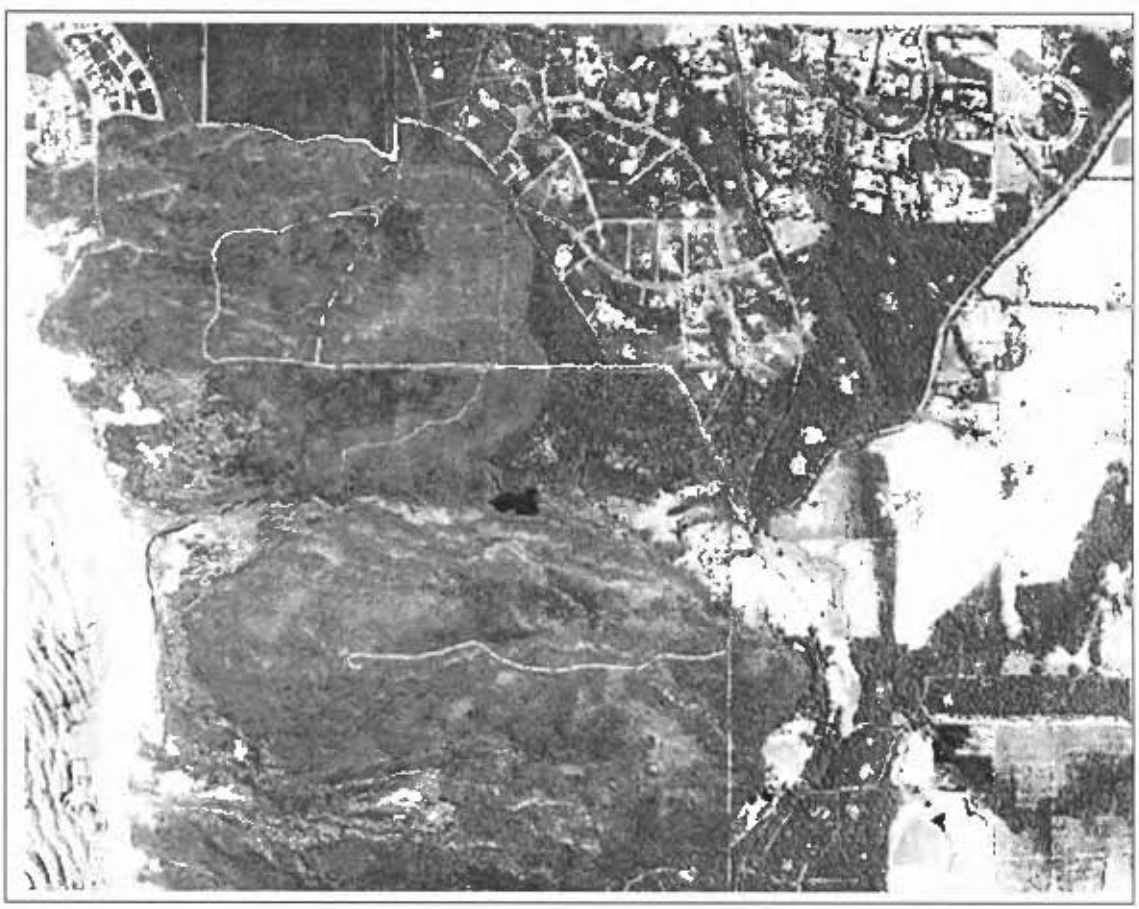


Fig 3.17 Satellite (Google Earth) image of Devil's Pool and surrounds.

Naturaliste Park, a nature conservation area administered by Conservation and Land Management (C.A.L.M). The site is coastal and lies within 1 kilometer of the sea. Devil's Pool is a seasonally permanent water body, a few meters deep, which is raised approximately 10 meters above sea level, and provides a temporary base level from which water then flows to the Indian Ocean (see plate 3.4).

Plate 3.4 Devil's Pool from northern ridge.

3.4.2.2 Local Geology

The Leeuwin-Naturaliste ridge is a steep sided ridge running from Cape Naturaliste in the north to Cape Leeuwin in the South. The ridge is a structure consisting of pre Cambrian granitic gneiss capped by laterite and calcareous sands (Lowry, 1967). This physiographic region forms part of the Perth basin which runs for approximately 1000 km along the West Australian coastline. Secondary Pleistocene limestones as well as sand dunes are also present in the region some of which are up to 150 m in thickness. A number of limestone caves are found throughout this geological feature and caves in the vicinity of the study site at Devil's pool are well documented. One in particular, Witchcliffe Rock Shelter, situated approximately 100m north of Devil's pool, and approximately 30m above the valley floor has been the focus of archaeological study, with an aboriginal inhabitation record dating back some 2000 years (Dortch, 1996).

3.4.2.3 Local Climate

The site falls within the winter rainfall region, with upwards of 90% of the rainfall falling in the winter months. The mean annual rainfall for the area is between 800mm and 1000mm (Bureau of Meteorology). The mean maximum summer temperature in the area is 29 degrees C and does not drop below a mean minimum of 10 degrees C. The winter temperatures fall to a mean maximum of 15 degrees C and a mean minimum of 5 degrees C.

3.4.2.4 Local Vegetation

The region adjacent to the study site and indeed the entire Leeuwin – Naturaliste ridge exhibits a complex system of vegetation types, as a direct result of variations in topography and microclimate variations brought about as a result of the 150m high ridge (Dortch, 1996; Beard, 1990) The ridge has direct influence on prevailing winds and effective precipitation (Pickett, 1997; Gentilli, 1972) sheltering vegetation from onshore winds and creating localized areas of both increased and decreased precipitation. Open heathland dominates the western slope of the ridge, where there is direct exposure to prevailing winds, while with a decrease in exposure, there is a shift towards low, open woodland containing *Eucalyptus marginata* (jarrah), *Agonis flexuosa* (peppermint) and various *Banksia* sp. As exposure to prevailing winds lessens, taller Jarrah trees form an open forest, until in the lee of the ridge, particularly in the south, *Eucalyptus diversicolor* (Karri) high open forest appears (Smith, 1973). A combination of variations in soils and landforms as well as seasonality of climatic conditions has lead to a diverse range of vegetation communities in the Boodjidup Brook catchment area. A vegetation survey by Smith (1973) in this catchment area identified a number of vegetation communities including *Acacia decipiens* with a herbland under storey, Jarrah-Marri (*Corymbia calophylla)* open forest, Kari high open forest and Jarrah open forest. *Agonis flexuosa* is an important constituent of deeper valleys, and is in fact found growing prolifically in close proximity to Devil's Pool. Other *Eucalyptus* sp., such as Flooded Gum (*Eucalyptus rudis)* and Forest Blackbutt (*Eucalyptus patens)* are found on low ground and damp areas

along river banks. Karri forest consists of trees taller than 30m in height and although it tends to grow in pure stands, the under storey is diverse with various *Banksia* sp., *Casuarina* sp., *Agonis* sp. as well as fern species such as *Pteridium esculentum* present. Jarrah open forest generally consists of trees 10 – 30m in height with an under storey of various *Banksia* sp., *Casuarina* sp., *Persoonia* sp. as well as species such as the Christmas tree (*Nuytsia floribunda)* and *Agonis flexuosa.*

3.4.2.5 Degree of Disturbance

The upper reaches of the Boodjidup Brook catchment area have been subjected to a degree of disturbance almost entirely through agricultural practices tied to the well established wine industry in the area. These practices include the removal of native vegetation from the catchment area, thereby affecting the flow regimes of rivers and streams in the area. Salinity issues appear not to be of immediate importance in this catchment area. The lower reaches of the catchment area remain fairly undisturbed as they fall within the boundaries of the Leeuwin-Naturaliste Park, which through careful management has managed to preserve the remnant vegetation of the area in a fairly pristine condition. To what extent the native vegetation in the region is a result of Aboriginal land practice in the area specifically with regards to fire remains a topic of debate, but certainly one worth consideration (Dortch, 2000).

Chapter 4 – Methodology

4.1 Field sampling techniques

Due to the variation in sediments and environments encountered in each study site, different sampling strategies were employed with the aim of collecting samples for laboratory analysis.

4.1.1 Bruno section

The majority of the sediments found at this site were dry aeolian sediments, and dry fluvial sediments, with only a portion of the stratigraphic sequence consisting of wet organic sediments. The organic sediments were fairly consolidated, limiting the techniques available. Given the fact that the site was also a deep section cut through a river bed, it was decided not to attempt the use of a vibracorer, and thus the sediments were sampled by hand (Plate 4.1). The face of the sedimentary sequence was cleaned and further exposed down to ground water level, thus exposing the lower organic unit. The various units from present ground surface level to the bottom of the sequence were identified according to various sedimentary properties. A representative sample from each of the sandy aeolian and fluvial sedimentary units was obtained, while samples from the organic, presumably lacustrine sediments were taken at a much finer resolution. In the organic unit 5 the stratigraphy was comparatively complex, and a sample from each of

the representative layers was obtained. In the more massive organic units 8 and 9, samples were obtained at 5cm intervals.

Plate 4.1 Sampling units 8 and 9 of the Bruno section by hand

Larger bulk samples were also obtained from the more organic units for the purpose of carbon dating. All sample depths were recorded, samples placed in airtight sample bags and clearly labelled.

4.1.2 Lake Michelle

As this site is a seasonal wetland, it was presumed that the sediments to be sampled would be wet and reasonably unconsolidated, thus allowing the use of a vibracorer, the functioning of which is described in much detail by Baxter (1996). This system allowed for the insertion, facilitated by high frequency vibrations, of a length of aluminium core tube vertically downwards into the sedimentary sequence (Plate 4.2), and the removal of a representative core of this sequence. The core tube was driven into the sediments as until progress was halted by more consolidated and/or coarse-grained material which inhibited the functioning of the vibracorer mechanism. The core tube containing the sampled sediment was then removed through the use of a tripod and pulley system (Plate 4.3), the workings of which are also described in Baxter (1996) (Fig 4.1).

Plate 4.2 The vibracorer in use.

Plate 4.3 Retrieval of a core using a tripod and pulley system at Lake Michelle, Noordhoek

The open ends of the core tube were then sealed and the core tube labelled in order to preserve the orientation of the core for later sub sampling. The core, still inside the aluminium core tube, was then transported to the laboratory intact.

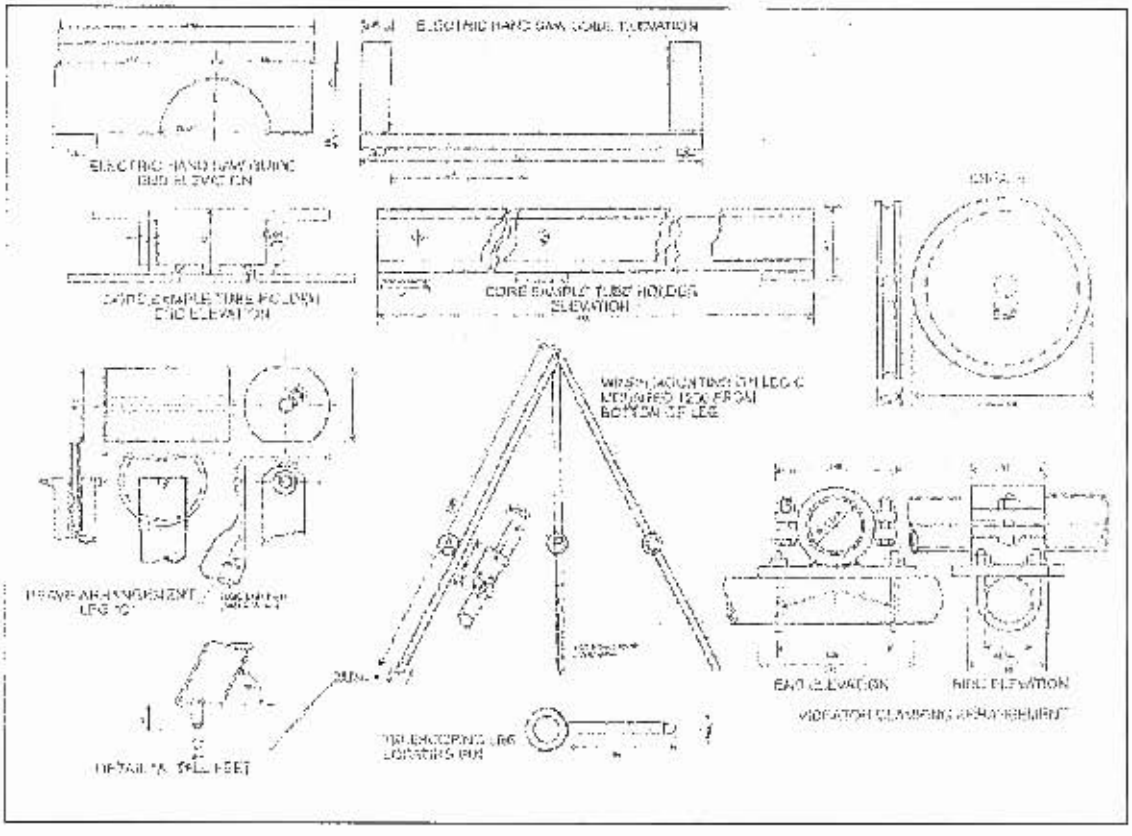


Fig 4.1 The blueprints for the vibracorer used in this thesis (from Baxter, 1999)

A circular saw mounted onto a sliding jig and used in conjunction with a tray system were then used to split the core lengthways in order to reveal two matching halves (Baxter, 1996). The two halves of the core were then placed into sealed plastic sleeves and each of them labelled accurately to maintain the orientation of the core until further sub sampling was undertaken.

4.1.3 Wambellup Swamp

On an initial visit to the study site, a boat was used to transport the coring equipment out to a central part of the swamp where coring could take place. However, on a subsequent

visit, the swamp system had dried out considerably, with no more than a few centimetres of water in isolated patches. Initial attempts to carry the coring equipment to the same sampling area failed until an inflatable mattress was used to drag the equipment across the thigh deep mud to the required area (Plate 4.4). The core sample was taken using a Russian corer which provides a "D" section core sample in 50cm lengths (Moore *et al.*, 1991) (fig4.2). To avoid contamination caused by pushing the corer down through the sediments and caused by the removal of the corer from the sediment, alternate 50cm lengths were taken from 2 different holes, placed within 50cm of one another.

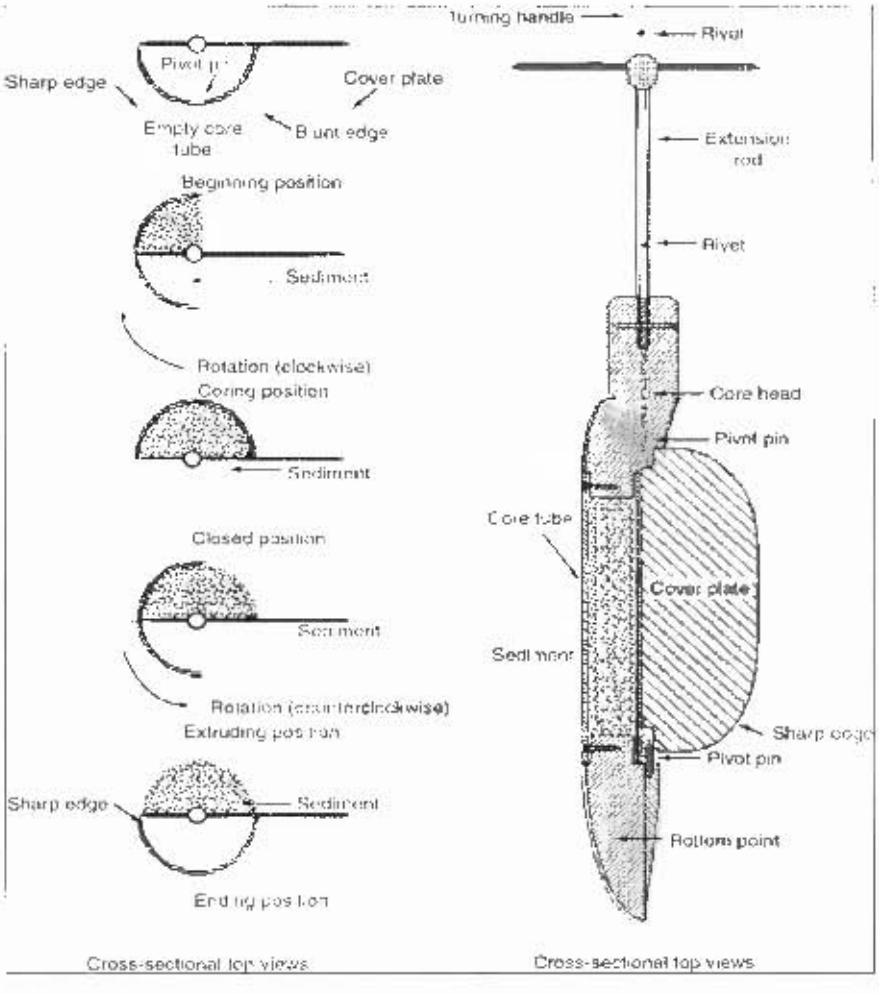


Fig 4.2 Diagram of Russian D-section corer.

After each sample was removed from the corer, the corer barrel was cleaned to prevent contamination in subsequent samples. Each 50cm length of sample was placed in a plastic tray and sealed in plastic wrap to maintain the integrity of the sample, and enable the sample to be transported intact. Each length of sample was labelled to record the depth from which the sample was taken and to preserve the orientation of the sample.

4.1.4 Devil's Pool

Due to the nature of the sediments to be sampled, and the necessity of portable sampling equipment, it was decided to use a Russian corer to sample this study site. A sampling site as close as possible to the edge of the water body was identified (Plate 4.5). As with Wambellup Swamp, to prevent contamination of the individual 50cm core sections, a number of holes in close proximity to one another were used alternately to obtain samples from different depths. The advantage of using a Russian corer as opposed to say a Hiller corer is the fact that the Russian corer has no auger head to disturb the sediments as it passes through, and is merely pushed down vertically into the sediment until the required depth is reached (Moore *et al.*, 1991). The disadvantage of this system is that the Russian corer can only be used in soft, wet sediments. As with Wambellup swamp, the 50cm core sections were placed in plastic trays for ease of transport, sealed with plastic wrap, and labelled to record depth and preserve orientation.

Plate 4.4 Sampling sediments at Devils's Pool with a Russian corer.

4.2 Laboratory Techniques

4.2.1 Core descriptions

Once the cores or samples were in the laboratory, a brief description of the stratigraphic sequence was undertaken. Each unit of the stratigraphic sequence was described in terms of colour, using a Munsell colour chart, from which a standard set of names is used to

describe the colour best matching that of the stratigraphic unit. Each unit was then described in terms of substrate type and texture, i.e. fine, medium or coarse sand, clay silt, peat or fibrous peat. Any inclusions found in the stratigraphic units is also noted, i.e. shells, wood, bone fragments, roots etc. This data was then represented graphically through the use of a computer graphics programme such as Corel Draw. The Tilia Graph package also allows for the inclusion of stratigraphy diagrams adjacent to the pollen frequency diagrams (Grimm, 1992).

4.2.2 Core sub-sampling techniques

The sub-sampling frequency for each sample site was decided upon based on the stratigraphy of each of the sedimentary sequences. In the Bruno section, for instance, there is a great variation in the thicknesses and complexities of the various stratigraphic units. Care was taken to obtain a representative sample from each of the units, and in the case of the more complex organic units 5, 8 and 9, the sampling frequency was reduced to 5 cm. In the other core samples, the visible stratigraphy was not as complex, with larger more uniform stratigraphic units. For these cores, a sampling frequency of one sample with every 20cm in depth was chosen. This leaves the option of revisiting the core or section samples at a finer resolution at a later stage should it be deemed necessary.

4.2.3 Carbon Dating

Samples for radiocarbon dating were obtained from each of the study sites. In each of the study sites, sedimentary units were identified within the sedimentary sequences which were suitable for radiocarbon dating. These units were deemed to have a high enough organic carbon content to enable dating to take place. Samples were submitted to the University of Western Australia dating laboratory in the case of the South West Australian study sites, and the Council for Scientific and Industrial Research (C.S.I.R) Quaternary Dating Research Unit (QUADRU) in Pretoria in the case of the Western Cape Research sites. As the dates obtained were conventional radiocarbon and not AMS dates, a relatively large amount of organic material was submitted for each date. A sample of 40 to 50 grams of material was submitted for each date to ensure the availability of 4 to 5 grams of organic carbon needed. Thus bulk samples were submitted from 5cm sections taken from the relevant organic units identified at each study site.

4.2.4 Pollen extraction techniques

For the purposes of pollen extraction, a $1cm^3$ sample was used. The sample was obtained by using a plastic syringe with the top removed. The top of the syringe was removed carefully using a sharp blade or Stanley knife. Accuracy is important in order to ensure that the samples are exactly the correct volume. Pollen extraction involved a number of steps aimed at concentrating the pollen grains in the sample in such a way that they could be more easily identified and counted. This process is one of elimination whereby all the material except for the pollen grains and a certain amount of the organic material is systematically removed from the sample, leaving only the material under investigation. A known volume of a standard concentration of a marker pollen grain, in the case of the Australian samples *Alnus* pollen was added to the sample to be able to monitor pollen recovery during the extraction process. This marker pollen is from a species known not to occur naturally in the sample. The steps below outline a standard method of pollen extraction (Moore and Webb, 1978).

- Sodium Hydroxide (NaOH) treatment: The addition of 10% NaOH acts as a dispersant, separating pollen grains from other material which may be present in the sample. Humic acids are also removed at this stage by decanting off the remaining supernatant

- Hydrochloric acid (HCl): The addition of 5% HCl enables the removal of carbonates, in particular free calcium carbonates from the sample material.

- Sieving: The sample is sieved through a 250 micron sieve in order to remove any large particles. All the pollen grains and a large proportion of the organic material are able to pass through this sieve, leaving behind large particles which may obscure pollen identification at a later stage.

- Hydrofluoric acid (HF): This step allows for the removal of silica particles such as fine sand, silt and clay which remain in the sample after sieving. HF is highly caustic and hazardous and this step must be undertaken with extreme caution.

- Acetolysis: This step allows for the removal of extraneous organic material in the sample. The Acetolysis solution is made up of a 9:1 ratio mixture of acetic anhydride and concentrated sulphuric acid (H_2SO_4). This solution is volatile and may become very warm after mixing and care should be taken when handling the acetolysis mixture.

- Staining: The addition of a small drop of aqueous safranine solution to each sample stains the pollen grains and some of the organic material in the sample. This allows for easier identification of pollen grains amongst the palyno-debris found in each of the samples.

4.2.5 Slide mounting techniques

For the purpose of pollen identification, a liquid slide mount, with sealed cover slip edges was chosen. The rationale behind this was the ability to rotate the pollen grains in situ on the microscope slide. This allows for easier identification of the pollen grains as all axes of the grain under observation can be viewed, allowing a three dimensional understanding of the pollen grain structure to be constructed. Glycerol/ phenol solution or silicon oil provided good liquid mounts, as their optical properties are adequate for pollen identification, with good light transmission and minimal distortion. The edge of the cover slip was sealed using glycerol jelly. The glycerol jelly prevented the microscope slides from drying out, as well as preventing the liquid mounting medium from leaking out from under the cover slip.

4.2.6 Pollen identification and counting techniques

Quaternary pollen analysis is integrally dependent on modern collections of known pollen types for the comparison and identification of the fossil grains (Moore *et al.*, 1991). Although the ideal would be the ability to identify each pollen type down to species level, due to morphological complexities, this is rarely possible (Baxter, 1996). The pollen grains present in the samples collected at the various sites were generally identified down to family level, and in some cases as far as genus level. This identification was aided by contemporary pollen reference slide collections. The reference slide collection initiated by J Sugden in 1985 as well as the more recent

micrograph collection arranged by S de Villiers housed in the Environmental and Geographical Science Department at the University of Cape Town the so-called Cape Town Collection of Pollen, aided in the identification of Western Cape taxa, while the reference slide collection housed in the School of Earth and Geographical Sciences at the University of Western Australia, aided in the identification of South-West Australian taxa. The pollen counting principles used were based on those outlined in Moore *et al.* (1991), which state that the number of pollen grains counted should be sufficient to give a good approximation of the relative abundance of pollen types which are of greatest interest to the study at hand. For the purpose of this study, the first 200 pollen grains on each sample slide were identified and counted. This number was deemed to be sufficient enough to provide a statistically meaningful data set, while remaining practical, especially in instances where pollen frequencies were very low, or pollen preservation poor.

4.2.7 Data processing and analysis

Raw data in the form of pollen counts was then entered into a general spreadsheet program such as Microsoft excel, with the depth value for each sample is entered as a row value, and the name of each taxonomic type identified is placed as titles for each row of data. The pollen count figures for each taxonomic type, for each sample are then entered into the spreadsheet matrix, including the zero values. The data was then saved as a "works" (.wks) file, a format that is readily identified by the tilia pollen data handling package. This file was then imported into the tilia programme (Grimm, 1992) for data

handling and manipulation. Each of the taxonomic groups recorded in the spreadsheet matrix was then assigned a code in order to identify the vegetation type, i.e. trees, shrubs, upland herbs, aquatics. By doing this, the programme was able to calculate the relative frequencies of different vegetation groupings within each sample. The programme was also used to calculate the relative frequencies of each of the identified taxonomic groups for each sample. The relative frequency of aquatic vs. terrestrial pollen could also be calculated. Once the data had been manipulated, the file was saved as a Tilia file (.til) and then imported into the Tilia Graph graphics package.

4.2.8 Graphic representation of data, dates and stratigraphy

The Tilia Graph package enabled the graphic representation of the data saved and manipulated in the Tilia programme. Through Tilia Graph, pollen frequency diagrams were plotted, providing graphic representation of the relative frequencies of each of the taxonomic groups identified for each depth related sample. These diagrams also provide graphic representation of the relation between the different taxonomic groupings, i.e. relative frequency of aquatic versus terrestrial representatives. Along with the pollen data, stratigraphy diagrams can also be produced adjacent to the pollen diagram, thus placing the pollen frequencies in context of the stratigraphic sequence. Further more, dates for the different stratigraphic units (where available) can also be added to the pollen diagram, thus providing an age context for the stratigraphy and relative pollen frequencies. To highlight trends within the pollen diagrams, the data is subjected to the standard CONISS nearest neighbour indices package. This package identifies zones

within the pollen diagram. These zones highlight trends within the data at various levels, from first order correlations, to fifth or sixth order correlations. It was decided to use the third order correlations to identify and highlight the zones within the pollen diagrams presented in this thesis.

4.2.9 Total Organic Content through Loss on Ignition (LOI)

The percentage of organic matter content present in each sample was determined through the use of the Loss on Ignition method (LOI) (Bengtsson and Enell, 1986). Samples weighing a few grams, and corresponding to those taken for pollen analysis were taken and placed in ceramic crucibles of a known weight. The weight of the crucible was recorded and each crucible marked with the sample number. The samples in their respective crucibles were placed in a drying oven overnight. The temperature of the drying oven was enough to remove all moisture from the samples, but not high enough to cause combustion of any material in the samples. These samples were then weighed, and the weight to three decimal places was recorded. The samples were then placed in a furnace, and their positions recorded, as any markings made on the crucible tended to be removed by the intense heat. The temperature of the furnace was set to approximately 450 degrees Celsius. The samples were left overnight and then removed from the furnace. They were allowed to cool in a desiccation jar to prevent the samples absorbing water from the atmosphere. Once the samples were cool, they were weighed again. The weight of the crucible was then subtracted from the total weight to obtain the residual weight of the sample. After ignition, the remaining sample should contain only inorganic material

and carbonates. The residual weight subtracted from the initial weight of the dry sample is equal to the weight of the organic material removed through combustion as the sample was subjected to high temperature. The weight of the removed organic material can be expressed as a percentage of the total weight of the original sample, thus the organic matter percentage.

4.2.10 Stable Carbon Isotope Analysis (δ C13)

Carbon isotope analysis of the Devil's Pool core from Western Australia was kindly provided through funding from the Science faculty of the University of Western Australia employing their standard protocols. The δ C13 values enable the researcher to determine the nature of the vegetation at that time in terms of C3 and C4 type plants, with strongly negative values in the region of -26‰ being indicative of chiefly C3 vegetation, and values in the region of -12‰ being indicative of chiefly C4 vegetation. Being able to determine the nature of the vegetation at a given time in terms of C3 or C4 dominance can give clues as to the climatic and environmental conditions prevailing at that time (Farquhar *et al.*, 1989; Rounick and Winterbourn, 1986).

Chapter 5: Results

This chapter presents the results obtained from each of the four study sites. This data includes a description of the sedimentary sequence at each site, an analysis of the Total organic Carbon through the sedimentary sequence at each site, as well as pollen diagrams generated through the palynological analysis of samples from each sedimentary sequence. $\delta^{13}C$ Values are also presented for Devil's Pool and for a few samples from the Bruno section. For raw data, see the Appendices.

Western Cape, South Africa

5.1 Bruno Section

5.1.1 Description of section

The total length of the section is 1090 cm. The section is quite strongly stratified, with the organic units being significantly different to the rest of the section in both colour and texture (see Table 5.1). The base of the section consists of alluvial sand intersecting with the water table. Above these units lies a unit consisting of dark organic clay material with some fibrous peat. Above this clay layer lie two units consisting of fine silt material with an organic lens. Above this lies a unit consisting of fine clay with some charcoal fragments.

Table 5.1 Description of Sediments from the Bruno section

Depth: cm	Description	Munsell notation
0 - 100	Unit 1 Aeolian fine sand	10 YR 5/1 Grey
100 - 240	Unit 2 Silt with some cross bedding	10 YR 5/1 Grey
240 - 480	Unit 3 Weakly laminated fine sand	10 YR 8/1 White
480 – 630	Unit 4 Silt	10 YR 3/1 Very Dark Grey
630 - 635	Unit 5a Laminated organic clay	2.5 Y 3/1 Very Dark Brown
635 – 640	Unit 5b Silty clay	10 YR 7/4 Pale Brown
640 – 650	Unit 5c Clay with charcoal	2.5 Y 7/2 Pale Grey
650 – 655	Unit 5d Silty clay	10 YR 7/4 Pale Brown
655 – 660	Unit 5e Laminated organic clay with charcoal	10 YR 2/1 Black
660 – 800	Unit 6 Silt	7.5 YR 4/1 Dark Grey
800 – 900	Unit 7 Silt with organic lens	10 YR 8/1 White, 2.5 Y3/1 Very Dark Brown Lens
900 – 980	Unit 8 Organic clay with fibrous peat layers	10 YR 4/2 Dark Greyish Brown
980 - 1090	Unit 9 Alluvial sand above water table	10 YR 5/1 Very Dark Grey

The upper units of the section consist of fine sand and silt with some fine laminations and cross bedding and are thought to be an aeolian element (Cornell, 2001)(see Fig 5.1).

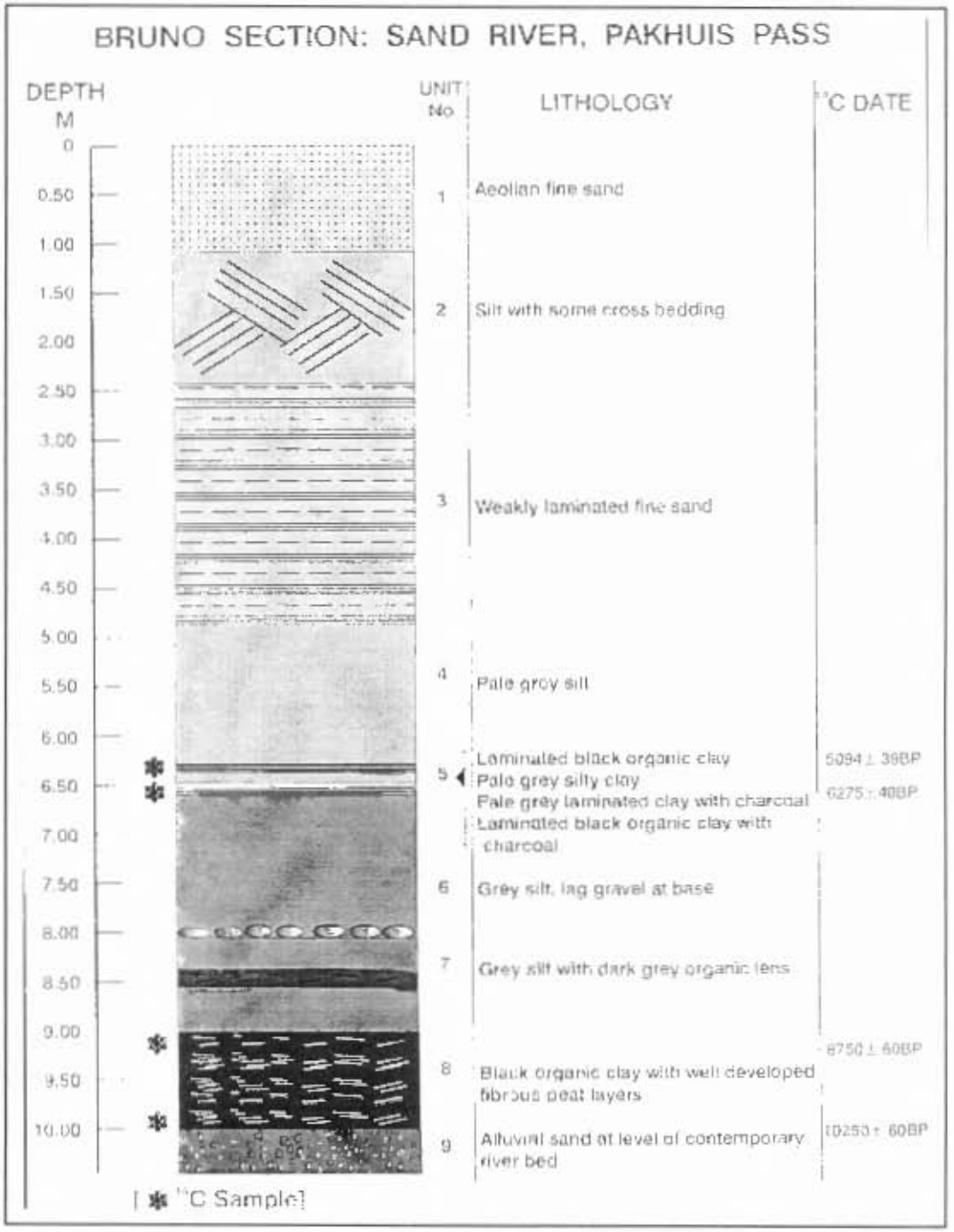


Fig 5.1 Description of Bruno Section illustrating position of Units 5, 8 and 9

5.1.2 Total Organic Carbon Content

The Total Organic Carbon content of these samples was calculated through a LOI method. As the Total Organic Carbon content of units 1 to 4 and units 6 and 7 were negligible, only the organic matter contents of units 5, 8 and 9 have been presented. Values for units 8 and 9 vary greatly (see Fig. 5.2), with a maximum value of 60.29% at a depth of 910 cm, and a minimum of 1.36% at a depth of 995 cm

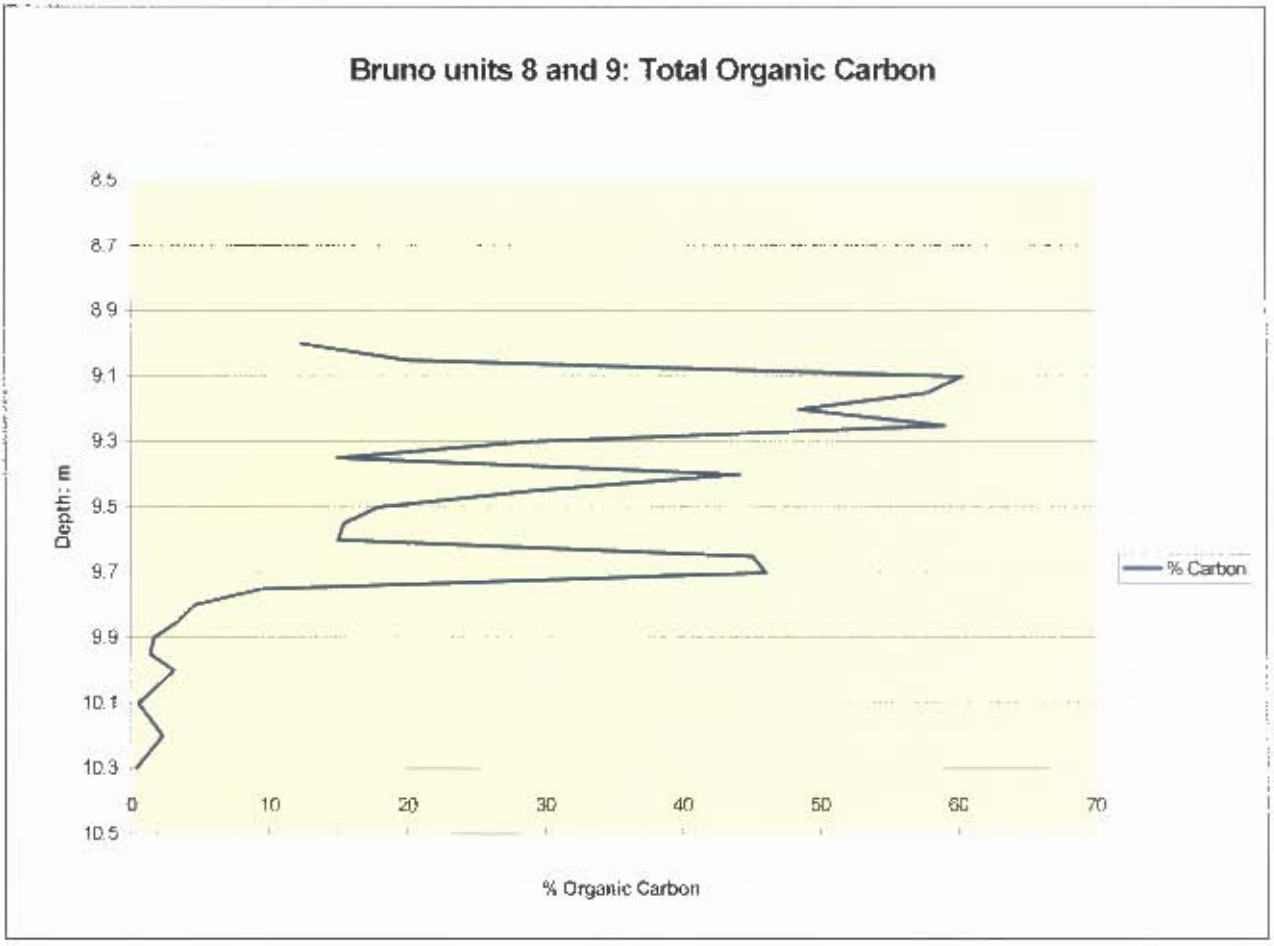


Fig 5.2 Total Organic Carbon content for Bruno section , Units 8 and 9

Although there are many fluctuations, the value are generally high, dropping off sharply from a depth of 970 cm to the base of the core where it terminates in organic poor, alluvial sand.

There is a degree of variation in the organic matter content of unit 5 of the Bruno section (Fig 5.3). Each of the sub-units in unit 5 differs quite markedly in organic matter content. Values range from a minimum value of 18.7 % at a depth of 635 cm to a maximum value of 65.4% at a depth of 650 cm.

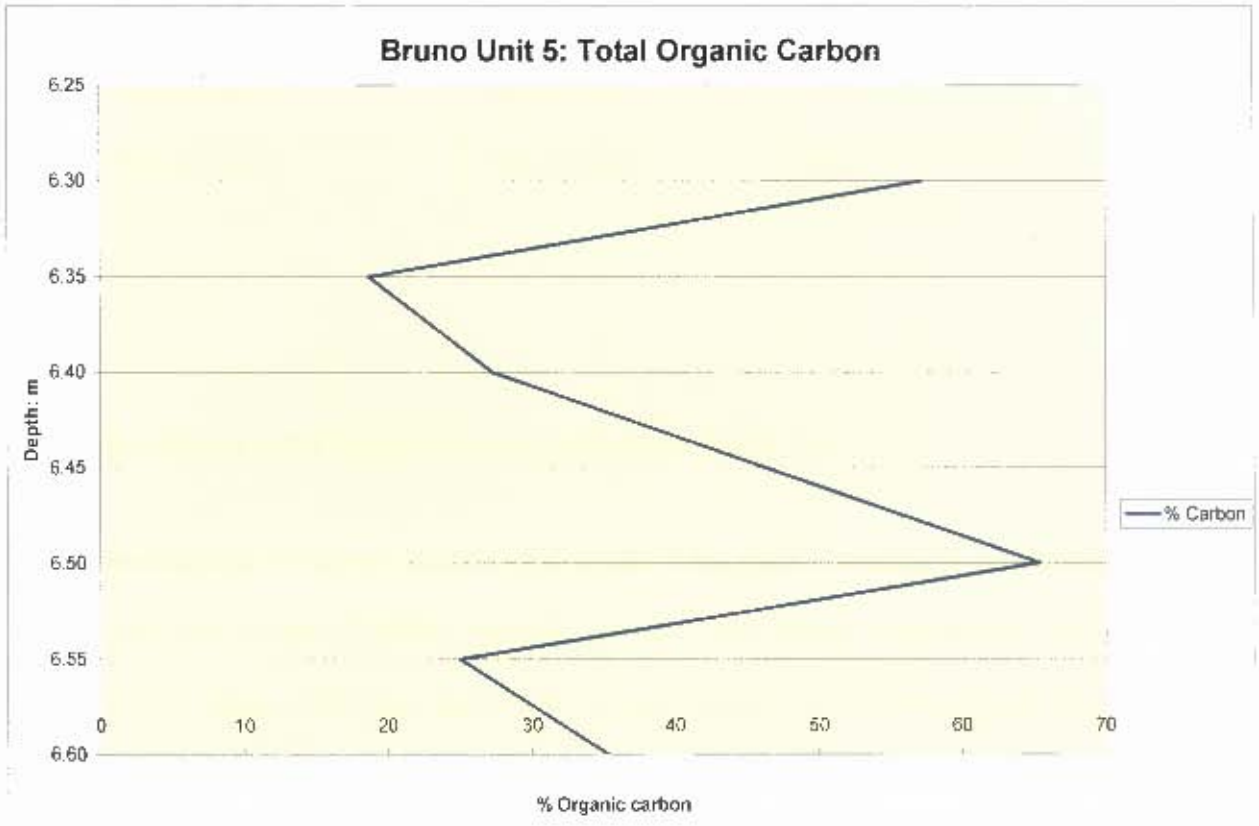


Fig. 5.3 Total Organic Carbon content for Bruno section, Unit 5.

5.1.3 δ13C for Bruno Section, Units 5 and 8

A small number of δ13C values were obtained for the samples which were radiocarbon dated. The values are all strongly negative and range between -30.1 [‰] and -26.6 [‰]

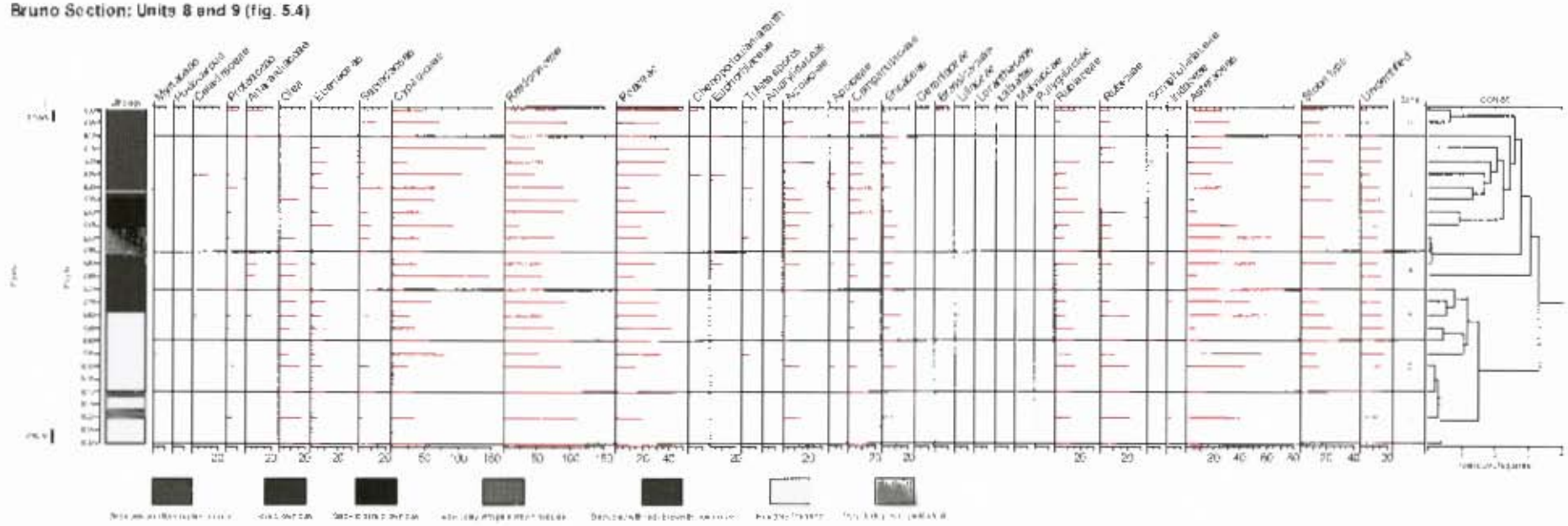
Table 5.2 δ 13C values for Bruno section, units 5 and 8

Unit	Depth	δ13C [per mil]
Bruno Unit 5	Top to 7cm	-30.1
Bruno Unit 5	25cm to 30cm	-29.3
Bruno Unit 8	Top to 5cm	-26.7
Bruno Unit 8	75cm to 80cm	-26.6

5.1.4 Pollen Diagram for Bruno Section, Units 8 and 9 (Fig 5.4)

The pollen diagram for Bruno section units 8 and 9 has been sub-divided into 6 units through the use of the CONNIS function in the Tilia Graph programme. Pollen preservation in these units was good with a total number of 32 pollen taxa being identified. A total of 24 samples from units 8 and 9 was subjected to pollen analysis, with a sampling interval of 5cm down to a depth of 10m after which a sampling interval of 10cm was applied as the stratigraphic units became less organic.

Bruno Section: Units 8 and 9 (fig. 5.4)



B8-9 Zone 1: 1030cm – 1010cm

A basal sample from this zone has been dated at 10 250 ± 60 B.P. (12 022±188 Cal yrs B.P.), placing the base of this zone in the late Pleistocene. Arboreal taxa are represented in this zone by *Olea.* Members of the Ebenaceae are also observed in this zone. Cyperaceae pollen is relatively abundant in Zone 1, but less so than Restionaceae pollen. Cyperaceae and Poaceae pollen decreases slightly in abundance towards the top of the zone, while Restionaceae pollen representation remains fairly constant throughout. Shrub pollen taxa are represented by Ericaceae, Rubiaceae, Rutaceae and Campanulaceae, while succulents are represented by the family Aizoaceae. Asteraceae pollen is fairly abundant in zone 1, but decreases toward the top of the zone. This decrease corresponds with the appearance and increase in *Stoebe*- type pollen (probably *Elytropappus rhinocerotis*).

B8-9 Zone 2: 1010cm – 990cm

There is continued representation of arboreal pollen (Olea, Ebenaceae) in zone 2. There is a sharp increase in abundance of Asteraceae pollen toward the top of the zone. Fluctuations in the abundance of Cyperaceae and Poaceae pollen are noted, with a general increase in representation through the zone. This increase in Cyperaceae is mirrored by fluctuations and a general decrease in the abundance of Restionaceae pollen. Small scale fluctuations in the representation of most of the herbaceous taxa are noted throughout this zone. There is a steady increase in the representation of the *Stoebe* -type pollen throughout the zone.

B8-9 Zone 3: 990cm – 970cm

The representation of arboreal taxa remains fairly constant throughout Zone 3, with a slight increase in the *Olea* pollen. This slight increase is paired with the appearance of Anacardiaceae pollen, which may represent an arboreal or herbaceous species. Fluctuations in the abundance of Cyperaceae, Restionaceae and Poaceae occur throughout the zone, with no significant net increase or decrease. Small fluctuations in the abundance of most of the herbaceous pollen taxa also occur throughout this zone. There is a general increase in the abundance of the Asteraceae pollen through this zone, which in turn is mirrored by a general decrease in the representation of *Stoebe*- type pollen.

B8-9 Zone 4: 970cm – 955cm

Arboreal taxa are still represented by *Olea* spp and Ebenaceae, but a reduction in the significance of Ebenaceae pollen towards the top of the zone is observed. Pollen representing the family Anacardiaceae is still present in Zone 4. A spike in the Cyperaceae pollen in the middle of the zone is mirrored to a certain extent by a dip in the pollen frequency of the Poaceae. Although there are some fluctuations, there is not much net difference in the pollen frequency of the Cyperaceae, Poaceae or Restionaceae from the bottom of the zone to the upper limit of the zone. Some minor fluctuations in the representation of most of the herbaceous pollen taxa are observed.

The appearance of Euphorbiaceae pollen, representing another succulent karoo element, may be of significance. A sharp decrease in Asteraceae pollen in the middle of the zone, followed by an increase toward the top of the zone is mimicked to a lesser extent by similar fluctuations in the *Stoebe*- type pollen frequency.

B8-9 Zone 5: 955cm – 910cm

There are fluctuations in the representation of arboreal taxa, with the disappearance and reappearance of *Olea* pollen at various stages throughout the zone. There is a general increase in Ebenaceae pollen representation, but an almost total absence of Anacardiaceae pollen. There are numerous fluctuations in the Cyperaceae, Restionaceae and Poaceae pollen frequencies, but no significant net increase or decrease occurs through the zone. There is a further appearance (but not continuous) of Euphorbiaceae pollen in Zone 5 which once again may be of significance. Numerous fluctuations in the representation of herbaceous pollen taxa occur through this zone. A general decrease in the abundance of Asteraceae pollen, with a significant decrease in abundance toward the middle of the zone is observed. Large fluctuations in the frequency and abundance of *Stoebe*- type pollen takes place, mimicking the fluctuations in Asteraceae pollen abundance (generally decreased), but at reduced amplitude.

B8-9 Zone 6: 910cm – 900cm

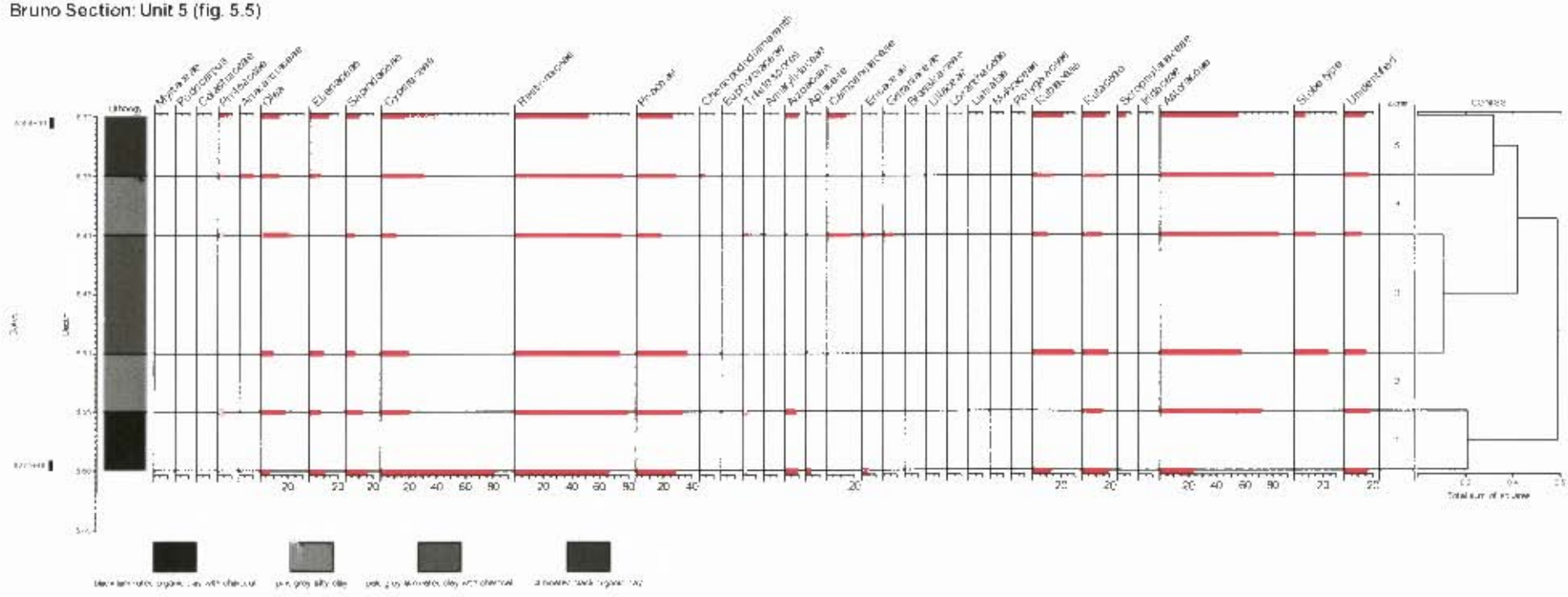
A sample from the top of this zone has been dated at 8750 ± 60 B.P. (9759±119 Cal yrs B.P.) placing the sediments from the top of this zone in the early Holocene. There is a

general decrease in arboreal pollen representation, with the disappearance of both *Olea* and Ebenaceae pollen. The disappearance of these arboreal taxa coincides with the reappearance of Anacardiaceae pollen. Fluctuations in the frequency of Cyperaceae and Restionaceae pollen are recorded, with an increase toward the middle of the zone, but then decreasing once more toward the top of the zone. This decrease toward the top of the zone is in conjunction with the reappearance of Chenopodiaceae pollen and with the disappearance of Euphorbiaceae pollen. There is a general increase in the frequency of Poaceae pollen in this zone. There is a general decrease toward the top of this zone in most of the herbaceous taxa with a few exceptions. Asteraceae pollen remains fairly significant and constant, but there is a general decrease in *Stoebe*- type through the zone.

5.1.5 Pollen Diagram for Bruno Section, Unit 5 (Fig. 5.5)

The pollen diagram for the Bruno Section Unit 5 has been divided into five zones through the use of the CONNIS function of the Tilia graph program (see Fig. 5.5). The condition of the preserved pollen in these sediments was good, with a total number of 32 taxa being identified. A total of six samples (one from each stratigraphic unit) from unit 5 were subjected to pollen analysis.

Bruno Section: Unit 5 (fig. 5.5)



B5 Zone 1: 660cm – 655cm

A sample from the base of this zone has been radiocarbon dated at 6275 ± 48 B.P., (7211±42 Cal yrs B.P.) temporally placing the sediments at the base of this zone in the mid Holocene. There is representation of certain arboreal taxa, such as *Olea* and Ebenaceae, with an increase in *Olea* sp. pollen toward the top of this zone. A sharp decrease in the prevalence of Cyperaceae pollen corresponds to a gradual increase in the prevalence of both Restionaceae and Poaceae pollen as well as a sharp increase in the prevalence of the Asteraceae pollen. Although represented, there seems to be a general decrease in the representation of many of the herbaceous taxa, such as the Ericaceae, Rubiaceae, Rutaceae and Apiaceae.

B5 Zone 2: 655cm – 650cm

Although arboreal taxa are represented in this zone, there is a general decrease in the representation of *Olea* pollen. Sapindaceae pollen is fairly well represented in this zone. Cyperaceae pollen representation remains fairly constant, as does Restionaceae, but a slight increase in Poaceae pollen representation is discernable in Zone 2. A number of the herbaceous taxa which are represented in Zone 1 are absent or decrease in prevalence in this zone, with the exception of the Rubiaceae and Rutaceae, which both show increased representation through this zone. This increase in herbaceous taxa is coupled with the appearance and increase in representation of the *Stoebe* type Asteraceae pollen.

B5 Zone 3: 650cm – 640cm

There is continued representation of arboreal taxa in this zone, with a gradual increase in the representation of *Olea* pollen throughout the zone. A gradual decrease in the representation of both Cyperaceae and Poaceae is evident, while the representation of Restionaceae remains fairly constant through the zone. There is a decrease in both Rutaceae and Rubiaceae pollen, which is mirrored by an increase in a number of other herbaceous taxa. A decrease in the *Stoebe* type pollen is mirrored by a corresponding increase in other Asteraceous pollen types.

B5 Zone 4: 640cm – 635cm

Arboreal taxa in Zone 4 are still represented by *Olea* pollen. Coupled with an increase in *Olea* is the appearance of Anacardiaceae pollen which may represent an arboreal or herbaceous element. There is an increase in both Cyperaceae pollen and Poaceae pollen, while the Restionaceae representation remains unchanged through this zone. A limited representation of Chenopodiaceae pollen is coupled with a general decrease in most of the herbaceous taxa, the Rutaceae and Rubiaceae being the exception. There is general a decrease in the *Stoebe*-type pollen representation in zone 4, while the representation of other members of the Asteraceae family remains fairly constant throughout.

B5 Zone 5: 635cm – 630cm

A sample from the top-most sediments of this zone has been dated at 5094 ± 34 B.P., (5836±61 Cal yrs B.P.) placing these sediments in the Mid Holocene. A general increase in representation of the arboreal taxa such as *Olea* and Ebenaceae corresponds with a decrease in Anacardiaceae pollen. An increase in Cyperaceae pollen is mirrored by a decrease in the Restionaceae and the disappearance of the Chenopodiaceae, while the Poaceae pollen representation remains fairly constant throughout this zone. The disappearance of some of the herbaceous taxa is followed by the appearance of others such as the Scrophulariaceae. Succulent karoo vegetation is represented in this zone by the family Aizoaceae. There is an increase in a number of the herbaceous pollen types such as both the Rubiaceae and Rutaceae, as well as increase in *Stoebe*-type pollen. These increases are mirrored by a decrease in representation of pollen of other members of the Asteraceae, even though Asteraceae abundance remains significant.

5.2 Lake Michelle, Noordhoek

5.2.1 Description of core

The core measured a total of 300 cm in length. The lower two units consist of sand containing some marine shell fragments, and charcoal fragments respectively. Above this is a unit consisting of sand interspersed with organic material. This unit was followed by

a number of units consisting of medium grained grey sand. The upper units of the core consisted of fibrous plant material in a matrix of organic clay (Table 5.3).

Table 5.3 Description of sediments from Lake Michelle

Depth: cm	Description	Munsell notation
0 - 5	Organic material with fibrous plant matter	5 YR 3/1 Very Dark Grey
5 – 15	Organic material	5 YR 3/1 Very Dark Grey
15 – 55	Sand unit	5 YR 4/2 Dark Reddish Grey
55 – 100	Sand unit	10 YR 4/3 Brown to 5 YR 7/1 light grey
100 – 110	Organic material with sand	5 YR 3/1 Very Dark Grey
110 – 210	Sand with some marine shells	5 YR 6/1 Grey
210 – 300	Sand with some charcoal	5 YR 4/1 Dark Grey

5.2.2 Total Organic Carbon Content

The Organic matter content values for the Lake Michelle core are generally much lower than those observed at the other study sites (Fig. 5.6). With the exception of a near surface sample with an organic percentage of approximately 41%, the values are much lower, ranging from approximately 1% at a depth of 30cm, to a value of approximately 10% at a depth of 280cm and 11% at a depth of 300cm. These low figures indicate a very low organic content, which may account for the extremely poor pollen preservation in a number of samples from this core.

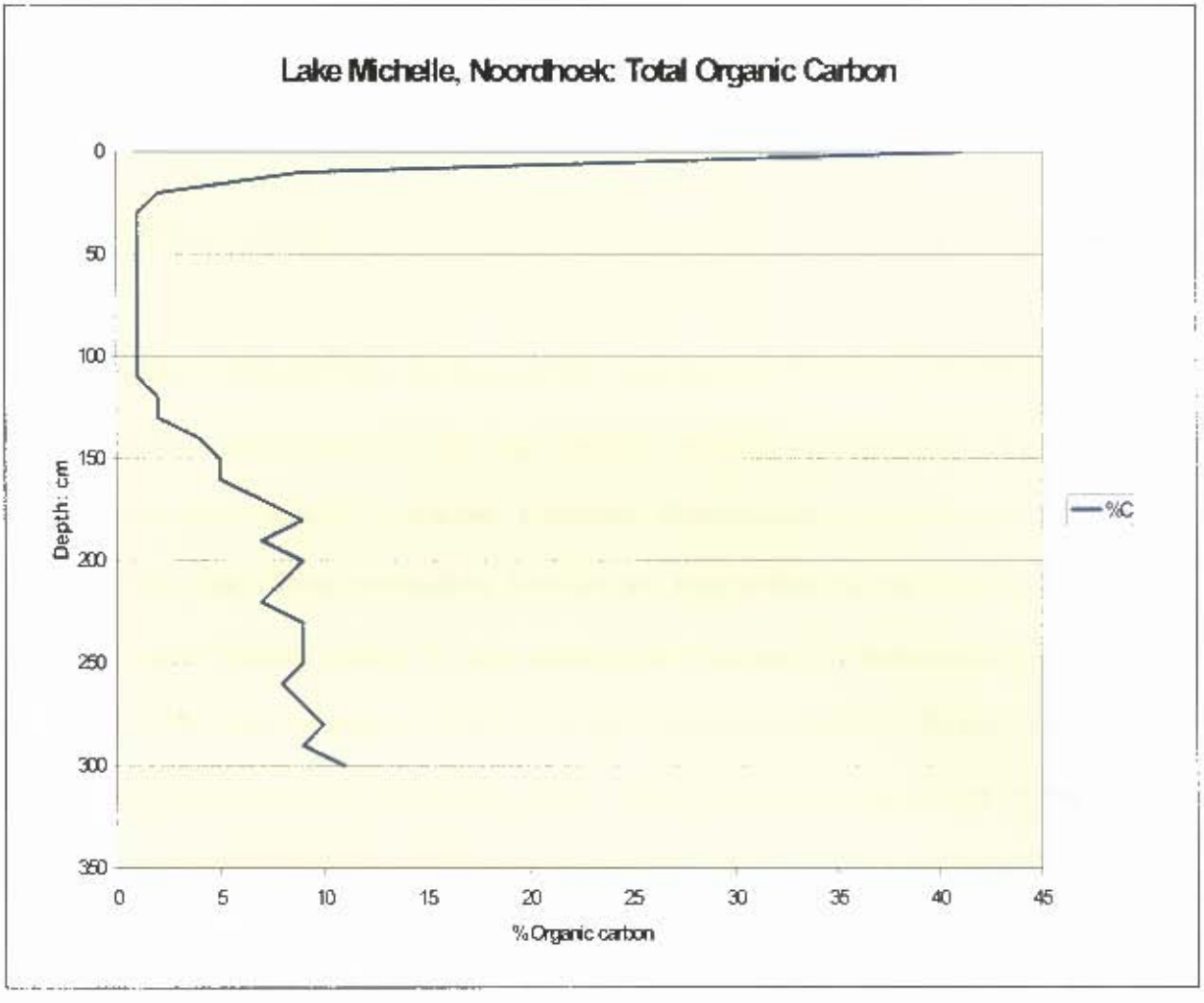


Fig 5.6 Organic matter content for Lake Michelle, Noordhoek.

5.2.3 Pollen Diagram for Lake Michelle, Noordhoek

The pollen diagram for the Lake Michelle core has been sub-divided into 8 zones through the use of the CONNIS function of the Tilia Graph program (Fig 5.7). Pollen preservation was variable, but generally poor, with a number of broken pollen grains and in some zones pollen was completely absent. A total number of 24 pollen taxa being identified. Samples were taken at 10 cm intervals, with a total of 31 samples being subjected to

pollen analysis. The large number of unidentified pollen grains resulted from poor preservation and damage.

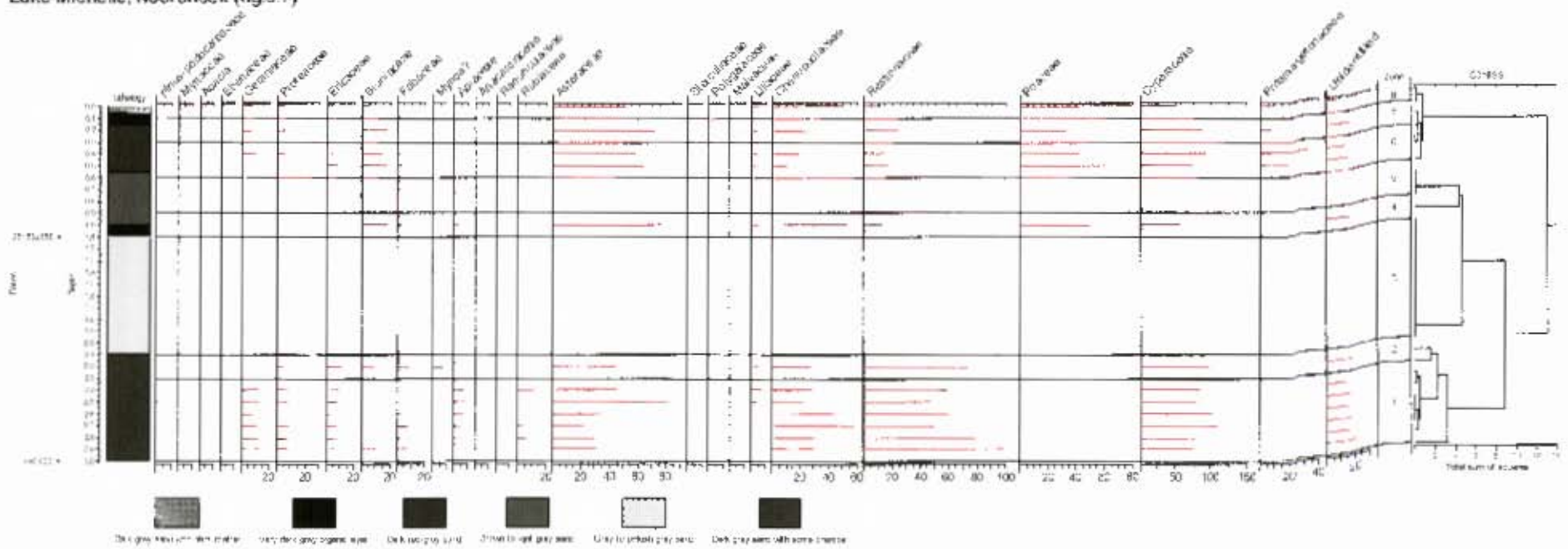
LM Zone 1: 300cm – 230cm

A sample of the sediments from the base of this zone has been dated at >40,000 B.P., being effectively a background or infinite age from the perspective of radiocarbon dating. Typical fynbos taxa, namely Proteaceae, Ericaceae, Restionaceae and Bruniaceae are present in this zone. Some herbaceous families are represented by the presence of Geraniaceae and Fabaceae pollen. A large spike in the frequency of Asteraceae pollen near the top of the zone corresponds with a corresponding steady decline in Restionaceae pollen. There is an absence of Rubiaceae pollen while Lilliaceae pollen appears in this zone. Chenopodiaceae pollen is prevalent throughout this zone, as is Cyperaceae pollen. A sharp decrease in pollen taxa as a result of poor pollen preservation in the sediments is evident toward the top of the zone. A very low frequency representation of *Podocarpus* pollen in this zone is of interest, although due to the low frequency, it may be difficult to infer wide ranging environmental conditions from its presence as pollen from this taxon is produced in very large quantities and dispersed over considerable distances.

LM Zone 2: 230cm – 210cm

Information pertaining to this zone is based on data from a single data point. Pollen is absent above and below 220cm depth (or present in very low numbers) making statistical

Lake Michelle, Noordhoek (fig.5.7)



analysis of the pollen frequencies impossible. At the single data point, relatively high frequencies of Asteraceae, Chenopodiaceae, Restionaceae and Cyperaceae are observed. Family representation is similar to that found in Zone 1, with Proteaceae, Ericaceae and Restionaceae representing some of the typical Fynbos taxa.

LM Zone 3: 210cm – 110cm

Pollen is either completely absent from the sandy, organic poor sediments in this zone, or preserved in such low numbers that statistical analysis of the pollen assemblage is impossible.

LM Zone 4: 110cm – 90cm

Pollen data in this zone are once again based counts from a single data point at 100cm depth. A sample of the sediment at this depth has, nevertheless, provided a radiocarbon age of 26150±150 B.P. (31051±344 Cal yrs B.P.), placing this sample within the last glacial, towards the end of MIS3. There is a general decrease in diversity at family level at this time. There is still significant representation of Asteraceae, Chenopodiaceae and Cyperaceae pollen, and this is linked with the appearance of Poaceae in relatively high numbers.

LM Zone 5: 90cm – 60cm

Pollen is once again completely absent, or present at extremely low frequencies in this sandy, organic poor zone, once again making analysis of the pollen assemblage impossible.

LM Zone 6: 60cm – 30cm

Pollen representing important fynbos taxa, i.e. Proteaceae, Ericaceae, Restionaceae and Bruniaceae are present in this zone. There is a spike in the Asteraceae pollen in the middle of the zone, decreasing toward the top of the zone. This pattern is mirrored by the Chenopodiaceae, which decreases markedly in the middle of the zone, and then recovers toward the top of the zone. An increase in Cyperaceae pollen prevalence corresponds with the appearance of freshwater aquatic taxa such as Potomagetonaceae and the increased importance of some herbaceous taxa, such as the Geraniaceae. Poaceae and Restionaceae are fairly constantly represented throughout the zone.

LM Zone 7: 30cm – 10cm

There is continued representation of typical fynbos taxa such as Proteaceae, Ericaceae, Bruniaceae and Restionaceae in Zone 7. Geraniaceae representation continues throughout

the zone, as well as a couple of other herbaceous taxa including the Liliaceae. Significant representation of Asteraceae occurs in this zone. An increase in Chenopodiaceae representation is mirrored by a corresponding decrease in Cyperaceae as well as a decrease in freshwater aquatic taxa (Potomagetonaceae). A general increase in both the Restionaceae and the Poaceae is noted.

LM Zone 8: 10cm – 0cm

Representation of some typical fynbos taxa such as the Proteaceae, Ericaceae, Bruniaceae and Restionaceae continues in Zone 8. Geraniaceae continues to represent the herbaceous taxa, as well as Liliaceae to a lesser extent. A further increase in the abundance of Chenopodiaceae pollen corresponds with a further decrease in the Cyperaceae pollen representation. A significant representation of the Asteraceae continues through this zone. Exotic taxa, such as representatives of the Myrtaceae, *Acacia* and what is identified as *Pinus* rather than *Podocarpus* all make an appearance in this zone. There is also a significant increase in the prevalence of Poaceae pollen, consistent with the introduction of exotic grass species. There is a corresponding decrease in the representation of Restionaceae.

Southwestern Australia

5.3 Wambellup Swamp

5.3.1 Description of core

The Wambellup Swamp core consisted almost entirely of dark, clay rich sediment, interspersed with some fibrous material, some fine sand and dark mottling toward the base of the core. The core is weakly stratified and the units are relatively uniform in texture and colour. The total core length is 265cm (Table 5.4).

Table 5.4 Description of sediments from Wambellup Swamp

Depth: cm	Description	Munsell notation
0 – 40	Fibrous matter with clay	2.5Y 2/0 Black
40 – 150	Fine clay material with some fibrous matter	2.5 Y 2/0 Black
150 – 240	Peaty material with some fibrous matter	5Y 3.5/1 Black
240 - 257	Fine clay material with fibrous matter and some fine sand	5Y 2.5/1 Black
257 – 265	Dark grey clay with dark mottling	5Y 3/1 Very Dark Grey 5Y 2.5/1 Black mottling

5.3.2 Total Organic Carbon Content

Total Organic Carbon content was calculated through the (LOI) method, and the results show extremely high values for organic matter (see Fig.5.8). The majority of the values lie between 60% and 80%, but peak at a depth of 160cm with a value of approximately

85%. These high values would be consistent with a swamp like environment. The percentage of organic matter drops dramatically toward the bottom of the core, to a value of approximately 9.5% at the base of core at a depth of 260cm.

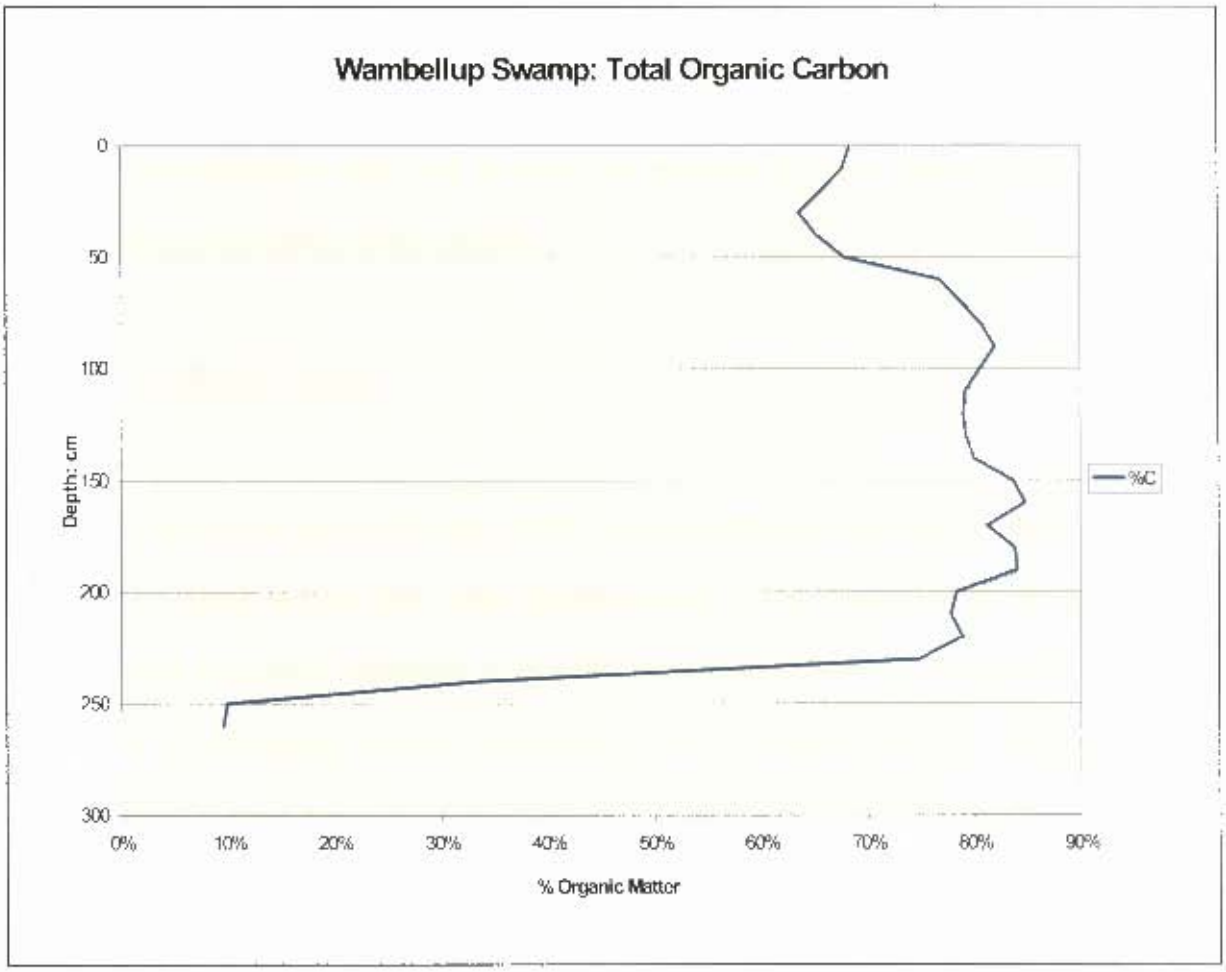


Fig 5.8 Organic matter content for Wambellup Swamp

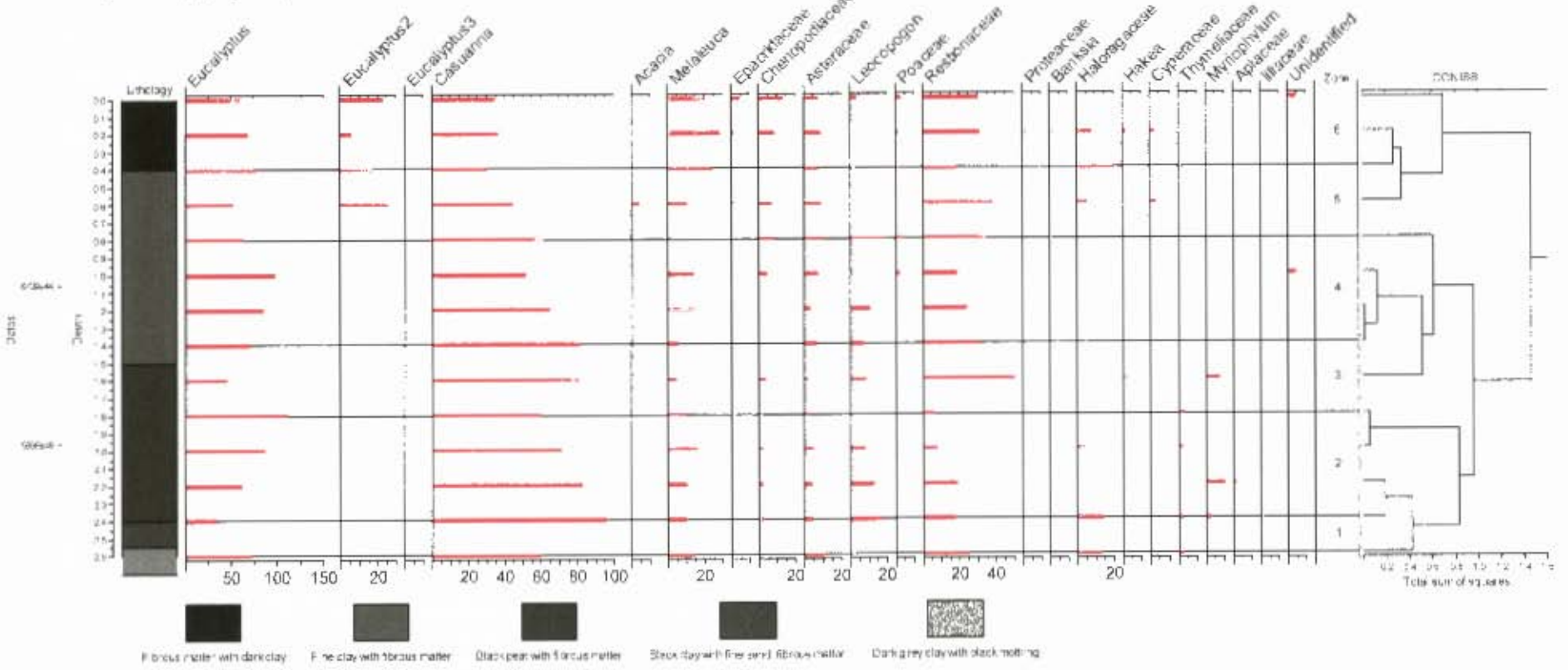
5.3.3 Pollen Diagram for Wambellup Swamp

The pollen diagram consists of six zones, which were defined through the use of the CONISS function in the Tilia graph pollen processing package (Fig. 5.9). Pollen preservation in the sediments was good, with 21 pollen taxa being identified at Wambellup Swamp. The stratigraphy of the Wambellup core does not present much variation in stratigraphic units and as such was sampled at 20cm intervals, with 14 samples being subjected to pollen analysis.

WS Zone 1: 260cm – 240cm

At present, there is no age for the base of this zone, but the sediments may be similar in age to those found at Two Mile Lake (Itzdien-Davey, 2004; Dodson et al., in prep.) which would give these sediments a mid-Holocene age. There is a decrease in the prevalence of *Eucalyptus* pollen (presumed to be *E. wandoo* and *E. marginata*) corresponding to an increase in the prevalence of *Casuarina* pollen in Zone 1. There is a slight decrease in the representation of *Melaleuca*.sp, Chenopodiaceae and Restionaceae pollen through this zone. Herbaceous plant taxa are represented by Asteraceae, *Leucopogon* (Epacridaceae), Haloragaceae and Thymeliaceae in the sequence.

Wambellup Swamp (fig 5.9)



WS Zone 2: 240cm – 180cm

A radiocarbon age has been obtained from a sample at a depth of 1.95m. The age of 6936 +- 36 B.P. (7791±54 cal yrs B.P.), places this sample in the mid-Holocene time period. There is a sharp increase in the *Eucalyptus* pollen representation in this zone, corresponding to a sharp decrease in the Casuarinaceae pollen. *Melaleuca* pollen is represented in this zone, but there is not much variation in the proportion of this representation. There is a steady decline in the representation of some of the herbaceous taxa such as *Leucopogon* and Haloragaceae, as well as that of the Restionaceae. *Myriophyllum* makes an appearance in this zone, but disappears again toward the top of zone, corresponding with the decline in many herbaceous types.

WS Zone 3: 180cm – 140cm

There is a general decrease in the prevalence of *Eucalyptus* pollen in this zone, mirrored by a general increase in Casuarinaceae representation and a slight decrease in *Melaleuca* prevalence. A point of interest in this zone may be the small increase in the abundance of *Chenopodiaceae* pollen and the greatly increased representation of *Restionaceae* pollen, although both of these taxa reduce in numbers once more toward the top of the zone. There are small fluctuations in most of the herbaceous plant taxa, but of note is the appearance and disappearance of *Myriophyllum,* an aquatic genus in this zone.

WS Zone 4: 140cm – 80cm

A sediment sample from a depth of 1.05m has been radiocarbon dated, yielding an age of 6709 ± 44 B.P. (7573±40 Cal yrs B.P.), placing this sample in the mid-Holocene period. There is a small increase followed by a decrease in the abundance of both *Eucalyptus* and *Melaleuca* pollen toward the top of the zone mirrored by the opposite trend in the abundance of *Casuarina* pollen. There is an increase in the Chenopodiaceae and Asteraceae pollen toward the top of the zone coupled with the appearance of Poaceae pollen. There is limited pollen representation of herbaceous taxa in this zone. A decrease in Restionaceae pollen towards the middle of the zone is followed by an increase toward the top of the zone.

WS Zone 5: 80cm – 40cm

There is a slight increase in the abundance of *Eucalyptus* pollen in this zone, but what is of interest is the appearance of a pollen type originally identified as *Eucalyptus*- type 2, which is subsequently, through further analysis of reference material is thought to be *Corymbia callophylla* (mari/ bloodwood). There is a sharp decrease in *Casuarina* pollen representation contrasting with a sharp increase in the *Melaleuca* pollen in zone 5. There is a decrease in the *Chenopodiaceae* pollen and a sharp increase in the *Haloragaceae* pollen linked with the appearance of *Cyperaceae* pollen at low concentrations. There is a sharp drop in the *Leucopogon* pollen frequency in this zone. There is a slight increase followed by a decrease towards the top of the zone in Restionaceae pollen.

WS Zone 6: 40cm – 0cm

There is a small decline in *Eucalyptus* pollen representation in zone 6, with an initial decrease and then increase in the *Eucalyptus*-type 2 pollen. There is a slight increase in *Casuarina* pollen, but not much variation in the abundance of *Melaleuca* pollen in zone 6. There is a noticeable increase in Chenopodiaceae pollen representation, mirrored by a sharp decrease in Haloragaceae pollen representation, but a slight increase in most of the herbaceous pollen taxa is observed. Small fluctuations in the Poaceae and Cyperaceae pollen representation occur through this zone.

5.4 Devil's Pool

5.4.1 Description of core

The core measured a total of 895cm in length. Near the base of the core is clay mixed with fine sand. The core consisted of fibrous peat and clay material near the surface, with the majority of the remainder of the core consisting of dark, organic peaty clays. The core is not strongly stratified with a number of the units being fairly uniform in colour and texture and only being differentiated by subtle changes (Table 5.5).

Table 5.5 Description of sediments from Devil's Pool

Depth: cm	Description	Munsell Notation
0 – 40	Clay with roots and fibrous plant matter	10 YR 2/1 Black
40 – 80	Fibrous peaty material with some clay	10 YR 2/1 Black
80 – 140	Dark peaty material with brown mottling	10 YR 2/1 Black 10 YR 2/3 Dark Brown
140 – 190	Clay and peat with mottling	10 YR 3/2 Very Dark Greyish Brown 10 YR 5/3 Brown mottling
190 – 240	Peaty clay with fibrous material	10 YR 3/2 Very Dark Greyish Brown
240 – 360	Peaty clay	10 YR 3/2 Very Dark Greyish Brown
360 – 380	Peaty clay	10 YR 2/1 Black
380 – 400	Peaty clay	10 YR 3/2 Very Dark grayish Brown
400 – 520	Peaty clay	7.5 YR 3/2 Dark Brown
520 – 660	Peat with increased clay and red precipitate	7.5 YR 3/2 Dark Brown
660 – 700	Peaty Clay	10 YR 3/2 Very Dark Greyish Brown
700 – 760	Clay	10 YR 2/1 Black
760 – 800	Peaty clay	10 YR 2/1 Black
800 – 840	Peaty clay	10 YR 3/2 Very Dark Greyish Brown
840 - 895	Peaty clay with fine sand	10 YR 2/1 Black

5.4.2 Total Organic Carbon Content

The Total Organic Carbon content for Devil's Pool fluctuates greatly with depth (Fig 5.10). With minimum values of 1,1% at a depth of 880 cm and a maximum value of 37,9% at a depth of 50cm. The general trend is an increase in organic matter content

toward the surface. This trend generally follows that of the increase in the Cyperaceae pollen through the core.

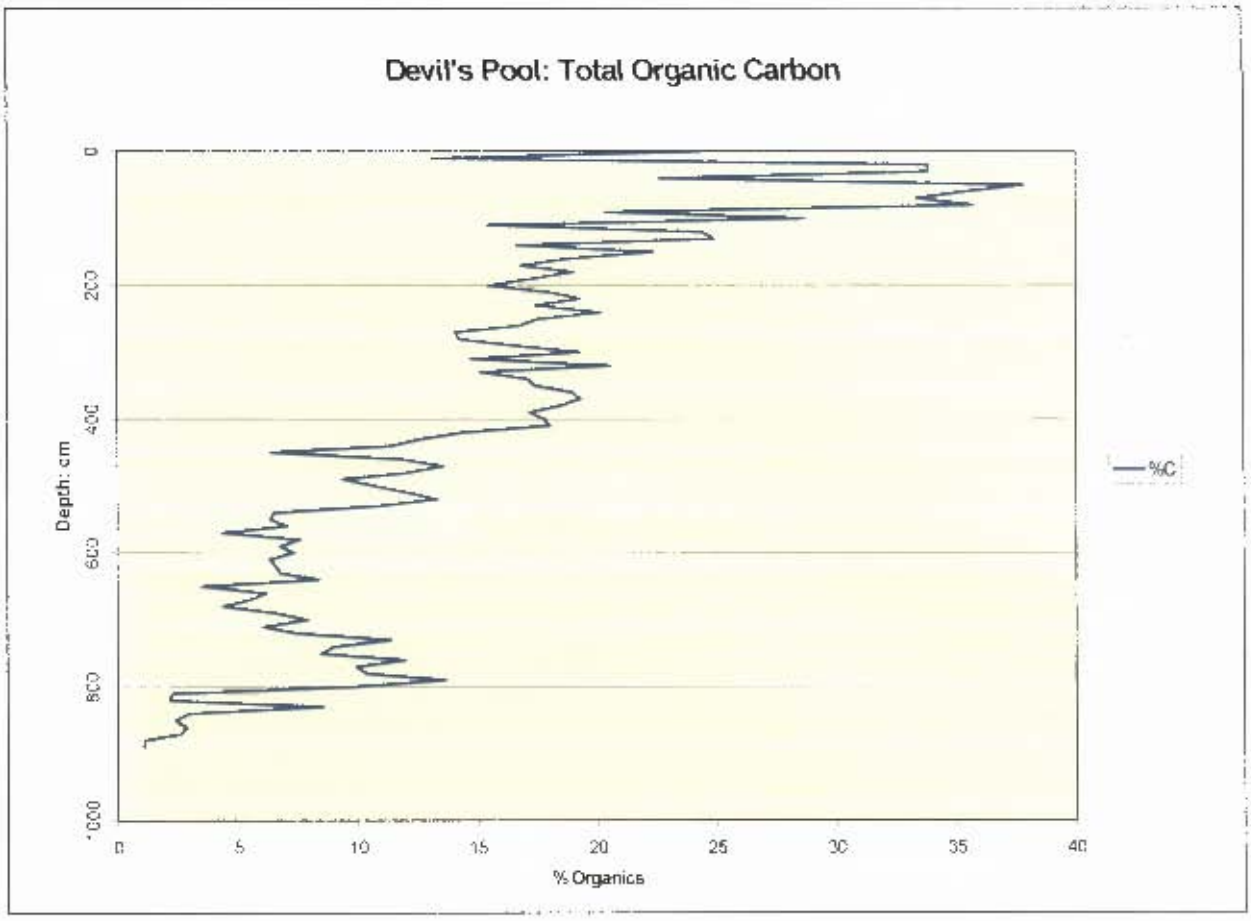


Fig 5.10 Organic matter content for Devil's Pool.

This increase in Cyperaceae, indicated by the sharp increase in Cyperaceae pollen representation, clearly contributes the majority of the organic matter accumulated in the sediments at the sampling site.

5.4.3 δ C_{13} values

The δ C13 values for the Devil's Pool core are all strongly negative values (Fig 5.11). The average value is -28.55 ‰; the maximum value is -25.15% at a depth of 540 cm, while the minimum value is -31,7% at a depth of 510 cm. These two values, especially the maximum value, stand out from the rest of the curve, and may be anomalies.

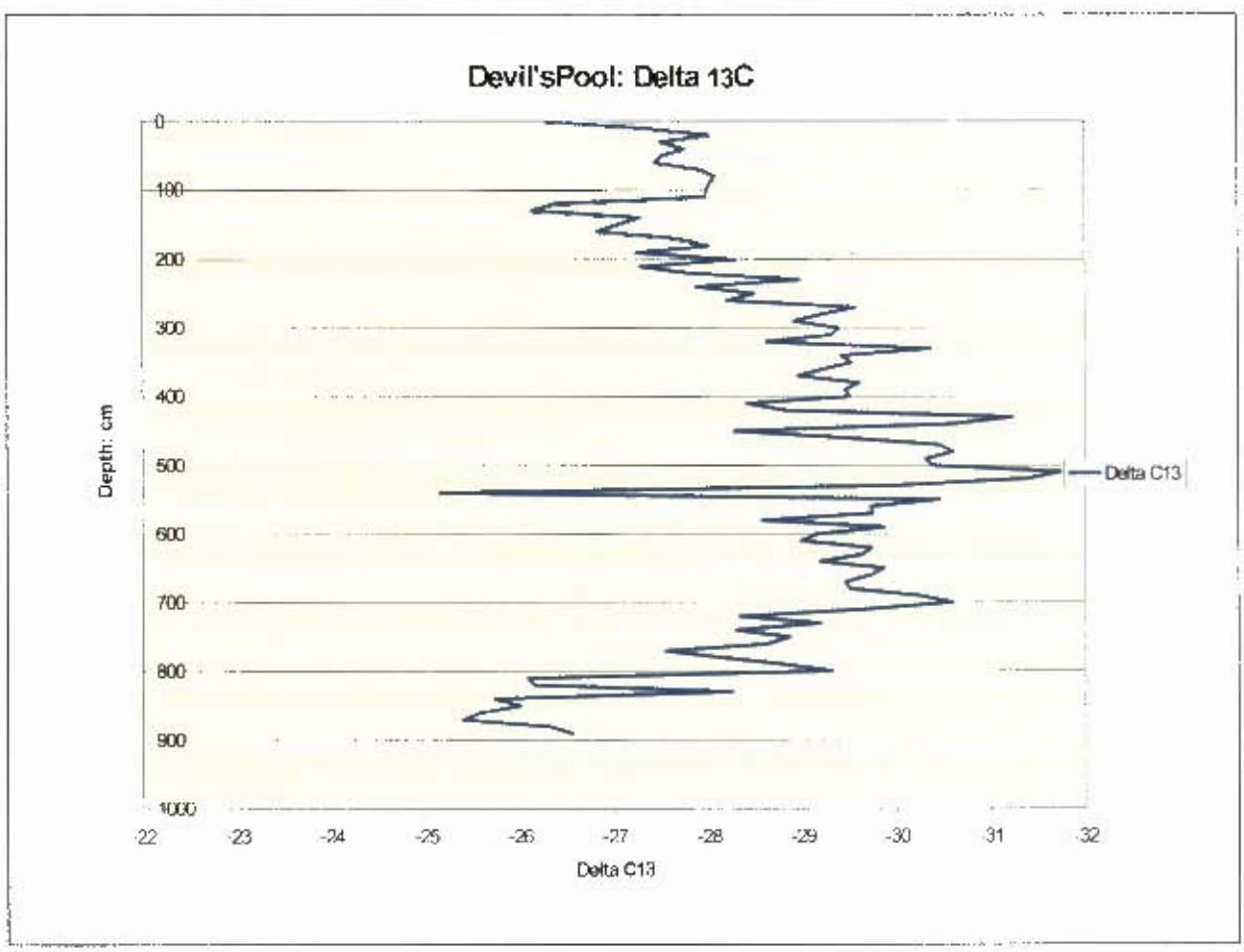


Fig 5.11 δ C13 values for Devil's Pool

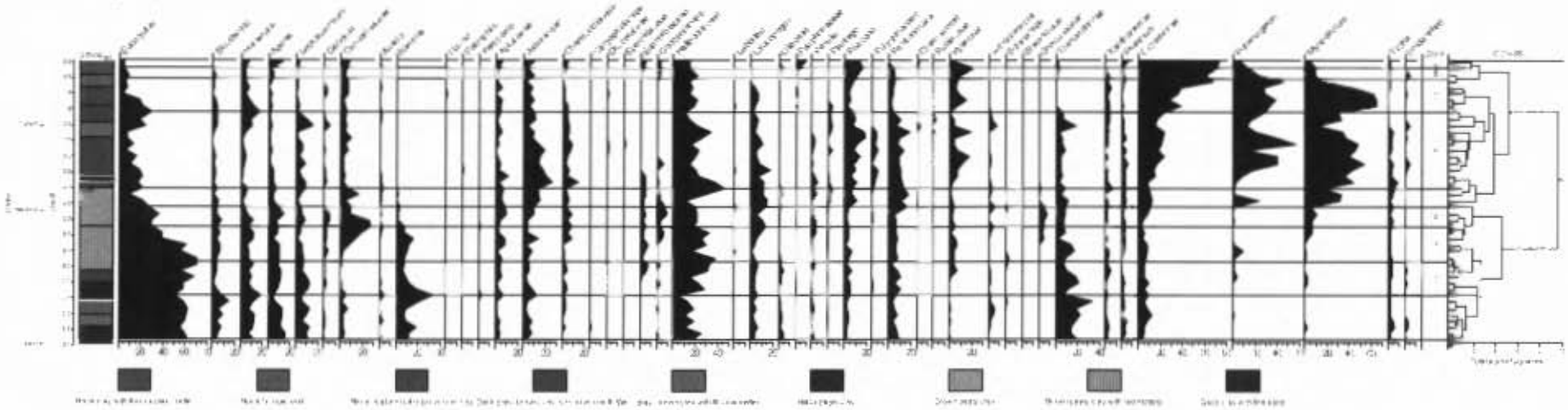
5.4.4 Pollen Diagram for Devil's Pool

The pollen diagram for Devil's Pool has been sub-divided into nine units through the use of the CONNIS function in the Tilia graph program (Fig. 5.12). These zones enable trends in the pollen assemblage to be observed. Pollen preservation in the sediments was excellent, with a total of 45 taxa being identified. A total of 45 samples was subjected to pollen analysis, with a sampling interval of 20cm.

DP Zone 1: 880cm – 740cm

Eucalyptus pollen is extremely well represented in this zone, and is by far the most dominant pollen type, with only small fluctuations in representation through the zone. There is also a relatively strong representation of a number of other arboreal species in this zone, including *Agonis, Melaleuca, Casuarina* and other 'Bloodwood' species. A sharp increase in *Banskia* pollen is evident toward the top of the zone. Haloragaceae pollen is also well represented through the zone. Restionaceae and Cyperaceae are well represented, but there is limited representation of Poaceae. Herbaceous pollen types are represented throughout the zone, including Asteraceae, *Leucopogon,* Apiaceae and a number of others at lower frequencies. There is very limited representation of aquatic pollen types in this zone, and they are in fact almost entirely absent from this zone.

Devil's Pool (fig 5.12)



DP Zone 2: 740cm – 630cm

There is strong representation of *Eucalyptus* pollen in this zone and as in Zone 1; *Eucalyptus* is the dominant pollen type. Once again there are only minor fluctuations in the representation of *Eucalyptus* pollen throughout the zone. As in Zone 1, arboreal species, including *Agonis* and *Melaleuca* are well represented. *Casuarina* however, decreases in representation in this zone. A sharp decrease in the representation of *Banksia* pollen is observed in this zone. There is constant, but limited representation of most of the herbaceous species in zone 2, while an increase in the frequency of *Haloragus* is noted. The representation of Cyperaceae and Restionaceae pollen is fairly constant throughout the zone. Aquatic pollen types remain almost entirely absent from Zone 2.

DP Zone 3: 630cm – 520cm

A marked decrease in representation of almost 50% is noted with regards to *Eucalyptus* pollen in this zone but, representation of other arboreal species remains fairly constant, with the exception of *Casuarina,* which shows a sharp increase toward the top of the zone. A small increase in *Banksia,* as well as some other herbaceous pollen types such as *Leucopogon* is observed in this zone, while the representation of other herbaceous taxa such as the Asteraceae remains fairly constant. A number of sharp fluctuations in *Haloragus* pollen is observed throughout zone 3. A small increase in Chenopodiaceae pollen in this zone may be of significance. A constant representation of Cyperaceae,

Poaceae and Restionaceae pollen occurs through this zone. A very small increase in the pollen of aquatic taxa occurs through zone 3.

DP Zone 4: 520cm – 460cm

There are only minor fluctuations in *Eucalyptus* pollen representation in this zone, and *Eucalyptus* pollen frequencies remain fairly constant, but at much lower levels than in Zones 1 and 2. There is a general decrease in most arboreal species pollen toward the top of the zone, this is especially true for the Casuarinaceae, which shows a marked decrease in abundance. The representation of most of the herbaceous taxa, including Asteraceae and *Haloragus* remains fairly constant in this zone. A further decrease in *Banksia* pollen is observed in Zone 4. Very small increases in the Restionaceae, Poaceae and Cyperaceae pollen types are discernable, and the representation of aquatic taxa increases marginally.

DP Zone 5: 460cm – 400cm

A radiocarbon date from the base of Zone 5 has yielded an age 3840 +-120 B.P. (4243±165 Cal yrs B.P.), placing the sediments at the base of this zone in the mid- to late Holocene.

There is a sharp decrease in *Eucalyptus* pollen in the middle of the zone which is mirrored by an increase in Casuarinaceae pollen representation.

A small increase in arboreal species pollen is observed toward the top of the zone. *Banksia* pollen decreases in abundance toward the top of this zone until it is almost

entirely absent. There is an increase in both *Haloragus* and Asteraceae pollen types towards the top of the zone, while the majority of herbaceous taxa remain fairly constant. Restionaceae, Cyperaceae and Poaceae pollen frequencies also remain fairly constant throughout Zone 5, while there is a further increase in aquatic species pollen representation, with a spike in *Potamogeton* pollen.

DP Zone 6: 400cm – 160cm

A radiocarbon age from sediments toward the top of the zone of 2100 ± 70 B.P. (2105±105 Cal yrs B.P.) has been obtained, placing these sediments in the late Holocene period. There are some fluctuations, but generally a constant representation of *Eucalyptus.* is observed, but at markedly lower levels than lower down in the sedimentary sequence. Representation of other arboreal species remains fairly constant throughout the zone, but a small increase in *Melaleuca* toward the top of the zone is observed. *Banksia* pollen is almost entirely absent from this zone. *Haloragus* and Asteraceae remain fairly well represented, but a general decrease in the levels of these pollen types is observed. A number of other herbaceous species such as the Tremandaceae and Rutaceae are more strongly represented in Zone 6. Poaceae and Restionaceae pollen types are more strongly represented in this zone, and there is a large increase in both the Cyperaceae pollen and aquatic pollen types such as *Myriophylum* and *Potamogeton* in Zone 6, with these pollen types becoming quite dominant in the sequence.

DP Zone 7: 160cm – 50cm

There is a further decrease in *Eucalyptus* representation to much lower levels than observed before. A decrease in *Melaleuca* pollen is also noted in this zone, but representation of other arboreal pollen types remains fairly constant throughout the zone, but at lower levels than before. Most of the herbaceous species are less well represented in this zone, with exception of perhaps the Rutaceae, Asteraceae and *Haloragus,* pollen levels of which remain fairly constant throughout. A decrease in the levels of Chenopodiaceae is notable. A small increase in Poaceae pollen representation is mirrored by a small decrease in Restionaceae pollen, while a sharp increase in Cyperaceae pollen is observed. There is an increased representation of some of the aquatic pollen types, but both the *Myriophylum* and *Potamogeton* pollen drop away toward the top of this zone.

DP Zone 8: 50cm – 20cm

Arboreal pollen types are represented at relatively constant levels through this zone, but at markedly reduced percentages compared to lower in the sequence. Haloragaceae pollen is still well represented throughout this zone, and there appears to be a fairly constant but limited representation of most of the herbaceous taxa in this zone. A small increase in Chenopodiaceae pollen is observed along with the reappearance of Euphorbiaceae. A small increase in Poaceae pollen representation is discernable, while the Restionaceae remains constant. There is also a spike in the Rutaceae pollen representation. There is a

further increase in Cyperaceae pollen representation, but a sharp decline in aquatic taxa represented by *Myriophylum* and *Potamogeton* is evident in this zone.

DP Zone 9: 20cm – 0cm

Eucalyptus pollen representation remains constant throughout this zone, but at low levels. There is a simultaneous increase in the pollen abundance of a number of the arboreal taxa such as *Agonis, Melaleuca* and *Casuarina* in Zone 9. A small increase in the frequencies of Chenopodiaceae, Asteraceae, Euphorbiaceae and Papillionaceae pollen types is also evident in this zone.

Haloragaceae pollen representation decreases slightly through this zone as does the Restionaceae pollen representation. Poaceae pollen levels remain fairly constant throughout Zone 9. There is a further increase in Cyperaceae pollen levels in this zone, mirrored by a significant further decrease in aquatic pollen frequencies.

Chapter 6: Discussion

This chapter discusses the results presented in the previous chapter, with the aim of providing insight into the environmental histories of the study sites suggested by the data. Each study site is discussed in turn, with the data being compared to previous relevant work conducted in the corresponding regions. Additional attention is given to the role of human interaction with the environment in the two regions, and to what extent evidence of human interaction with the environment is apparent when studying pollen diagrams.

6.1 Western Cape, South Africa

6.1.1 Bruno Section

6.1.1.1 Units 8 and 9:

Radiocarbon ages (calibrated dates in brackets) bracketing this segment of the Bruno section of 10250 ± 60 B.P. (12022±188 yrs B.P.) and 8750 ± 60 B.P. (9759±119 yrs B.P.) place units 8 and 9 in the early Holocene. The proximity of the Bruno site to the Pakhuis hyrax midden site (within 10 km) investigated by Scott (2000), Scott and Woodbourne 2007a,b) means that a direct comparison of palynological data from the two sites is possible and useful. There are, however, fundamental differences between the characteristics of the two sites that need to be kept in mind when comparing these data. The proximity to water of the Bruno site, particularly during periods of peat formation, in

comparison to the absence of permanent water at the Pakhuis Pass site, means that the pollen data from the Bruno section may be skewed toward reflecting more mesic conditions than temporally comparable data from the Pakhuis Pass hyrax middens. This may mean that the pollen data at Bruno do not fully reflect regional climate signals, but rather changes in very localised conditions. It is therefore necessary to carefully scrutinize the palynological evidence from the Bruno section in order to decide what evidence may be climate related and which not. For instance, the presence of Cyperaceae pollen in relatively high frequencies is a good indication of the presence of at least semi-permanent water however, the fluctuations in the frequencies of Cyperaceae pollen may not be linked to climate change, but to changes in the stream bed characteristics (meandering channels). Fluctuations in Cyperaceae pollen may also be linked to both increases and decreases in runoff. Decreases in runoff would mean a reduction in suitable environment for Cyperaceae growth, while increases in runoff would mean a more energetic flow regime and also a subsequent reduction in suitable environments for Cyperaceae growth.

The pollen types in units 8 and 9 of the Bruno sequence indicate a mix of typical fynbos families, such as the Proteaceae, Ericaceae and Restionaceae mixed with some succulent karoo elements such as the Aizoaceae, high proportions of Asteraceae and to a lesser extent, Euphorbiaceae. Arboreal elements such as *Olea* and Ebenaceae are indicative of thicket vegetation. Scott & Woodbourne (2007a,b) discusses the onset of generally warm, relatively dry conditions by approximately 9000 B.P., but with variability and many

interspersed moist events. This evidence would also seem consistent with the mixed picture emerging from the Bruno section.

In Zone 1, the presence of Aizoaceae (representing karroid succulents) and Asteraceae, coupled with the marginal decrease in Cyperaceae may be indicative of warm and slightly drier conditions. However, the presence of some arboreal taxa, such as *Olea* and Ebenaceae may indicate moister episodes or events, or may simply be indicative of the availability of water locally. Restionaceae remains important, but may be indicative of deep sand profiles in the immediate vicinity. Similar environments are extrapolated for Zone 2, with the exception of an increase in Poaceae and Asteraceae and a small peak in Aizoaceae pollen which may be indicative of slightly drier conditions. The reduced importance of Aizoaceae in Zone 3, coupled with the small increase in *Olea* and small increases in the frequencies of a few of the herbaceous pollen types possibly indicate a moister phase in the sequence, then drying toward the top of the zone as the Aizoaceae and Asteraceae numbers recover. The data in Zone 4 may be skewed by a spike in the Cyperaceae pollen, which may be indicative of a change in local conditions rather than a regional climate signal. The slight increase in the Aizoaceae as well as the appearance of Euphorbiaceae and the disappearance of the Proteaceae may hint at slightly more xeric conditions around this time. This may be a transitional period, as *Olea* numbers remain fairly constant as do a number of the herbaceous taxa, although *Olea*, as a tree is relatively long-lived and could be resilient to short-term dry phases. Scott and Woodbourne (2007a,b) discusses the shift towards more karroid conditions by approximately 8000 yrs B.P. at the Pakhuis Pass site, with increases in Asteraceae and reductions in some of the fynbos elements such as the Ericaceae. Although there is much

variability in Zone 5, the general trend in this zone would seem to confirm this interpretation. Except for a few short-lived peaks in pollen frequencies, there is not much variation in the general importance of the Restionaceae, Poaceae and Cyperaceae. There is, however, an increase in the prevalence of the Aizoaceae and, taken together with the presence of Euphorbiaceae and the simultaneous appearance of Chenopodiaceae/ Amaranthaceae this could be indicative of more intensive drying. This is supported by the much reduced prevalence of *Olea* in this zone. Local moisture may be the reason for the perseverance of a number of the herbaceous species as well as the Ebenaceae. This general drying phase is further reinforced in Zone 6 which once again is consistent with Scott and Woodbourne's (2007a,b) study, suggesting a period of greater aridity at Pakhuis Pass extending from 8500 B.P. to approximately 5000 B.P.. The absence of arboreal taxa such as *Olea* and Ebenaceae toward the top of Zone 6 coupled with the appearance of Chenopodiaceae/ Amaranthaceae, as well as the reduction in Ericaceae would support an argument for a drier period.

6.1.1.2 Unit 5:

Radiocarbon ages for this unit of the Bruno sequence of 6275 ± 48 B.P. and 5094 ± 39 B.P. place Unit 5 in the mid-Holocene. Based on evidence from the Pakhuis Pass hyrax midden site (Scott and Woodborne, 2007b) and various proxies from the Elands Bay region (Cowling *et al.*, 1999; Meadows *et al.*, 1996), this was a period typified by warmer and more xeric conditions than today. As with units 8 and 9, the presence of Cyperaceae throughout unit 5 may be an indication of the constant presence of fresh water in the

immediate vicinity. However, a climate-driven interpretation of fluctuations in Cyperaceae pollen may once again be misleading. Scott and Woodbourne (2007a,b), in particular, argues for xeric, more karoid conditions at Pakhuis pass from approximately 8500 B.P. to 5000 B.P.. Zone 1 of Unit 5 of the Bruno section appears to support this evidence. Aizoaceae pollen is still present in this zone and along with an increase in Asteraceae, suggests more karroid conditions. Local conditions and the presence of water may be a key factor supporting the presence of arboreal taxa and some of the herbaceous species. Scott and Woodbourne (2007a,b) discuss the replacement of Aizoaceae and karroid taxa with Asteraceae and more grasses from 5000 B.P. onwards, indicating more mesic conditions. This sequence of events would appear to have started a little earlier at the Bruno site than at the Pakhuis site, although there are constraints to temporal resolution of the chronology at both sites.

Zone 2 shows a decrease in the importance of Aizoaceae coupled with an increase in Poaceae and several other herbaceous taxa, and is in agreement with the sequence of events described by Scott & Woodbourne (2007a,b).

Zone 3 seems to indicate even more mesic conditions, with the absence of Aizoaceae and other succulent taxa pollen types. The increase in *Olea* as well as the appearance of a number of the herbaceous taxa would further support this.

These more mesic conditions carry through into Zone 4 of Unit 5, with a drying trend toward the top of the zone typified by the decrease in a number of the herbaceous taxa and *Olea* coupled with an increase in Poaceae. The appearance of Chenopodiaceae in Zone 4 may also lend further weight to this argument. Localised moisture would seem to have supported the increase in Cyperaceae and a few of the other herbaceous taxa, such

as the Rubiaceae and Rutaceae. It is difficult to typify the climatic conditions associated with Zone 5 of the sequence as a number of taxa, expressing opposed climate signals increase toward the top of the zone. The arboreal taxa, such as the Ebenaceae and *Olea* increase, indicating more mesic conditions, however, Aizoaceae reappears indicating more xeric conditions favouring the karroid elements. There is also an increase in a number of the herbaceous taxa, and a small decrease in the Asteraceae, thus on the balance of evidence, mesic conditions may have persisted in Zone 5 with a slightly wetter phase than that experienced in Zone 4.

Thus it would seem as though the evidence presented for the Bruno section broadly reinforces the evidence from the Pakhuis Pass hyrax midden site. With drier and warmer conditions persisting from the early Holocene through into the mid-Holocene, with more mesic conditions persisting from the mid-Holocene onwards. This also supports Scott and Woodbourne's (2007a,b) contention that, although there are general trends in the climatic signal, there is much variability in the data, giving a much more complex picture of climate change in the region. This stands in contrast to high altitude swamp evidence from the Cederberg, which showed very little variability in the palynological evidence for the Holocene period (Meadows and Sugden, 1991; Meadows and Sugden, 1993). This contrast may be explained in terms of regional and local topography, with higher and less variable rainfall being experienced at the high altitude wetland, in contrast to the lower altitude Pakhuis Pass and Bruno sites in the lower lying rain shadow of the Cederberg (Scott and Woodborne, 2007b). The pollen evidence from both the Pakhuis Pass and Bruno section is consistent with the pattern suggested by Cowling *et al.* (1999) describing Asteraceous fynbos with proteoid and ericoid elements being replaced by the

development of thicket mosaic, with a dynamic mixture of succulent karoo and dry mountain fynbos on a low soil moisture landscape (Scott and Woodborne, 2007b).

6.1.2 Lake Michelle, Noordhoek

Two radiocarbon ages (calibrated dates in brackets) have been obtained for this section, one a basal date of > 40,000 B.P. and another at a depth of approximately 110cm of 26150± 150 B.P. (31051±344 yrs B.P.). A number of concerns surrounding these dates and other concerns surrounding observations made regarding the stratigraphy of the core itself need to be addressed when interpreting the pollen record from this site. The basal age of > 40,000 B.P. is an infinite age in terms of radiocarbon dating and therefore not a true reflection of the age of the sediments. The age of 26150±150 B.P. (31051±344 yrs B.P.) at 110cm depth indeed suggests that a large proportion of the sediments in this core pre-date the period of time considered to be the LGM.

The Lake Michelle site is at present, and has been over recent geological time, a coastal site close to current mean sea level and, as such, in all likelihood has been subjected to the direct influence of sea level fluctuations over time. As there is evidence of more than one hiatuses in the pollen record for this site, it is also probable that the sediment accumulation record is discontinuous. Sea level inundations may have removed sediment from the site, with accumulation recommencing following sea level retreat. This situation could result in geologically younger material being placed directly above much older

material, with material separating the younger and older sediments being absent. This situation has also been implied for two other study sites examined by the author at both Betty's Bay and Cape Point, where material dated at > 40 000 B.P. (background age for carbon dating) was found at relatively shallow depths directly beneath much younger material. If this were the case at Lake Michele, then the pollen record would not be a true reflection of climatic changes over a set time period, but rather a reflection of both local and regional factors other than climate, with factors such as sea level having a direct influence on local salinity and moisture availability which would reflect in the local plant communities.

The answers to these concerns may lie in a greater number of dates for the sediments, and perhaps a change in dating techniques in order to bracket any events other than climate which may have had an impact on the study areas. It is possible that the high proportion of sand within the core would lend itself to some form of luminescence dating. This however would necessitate the re-sampling of the sample site and modification of the preparation techniques used to prepare samples for dating. This form of dating would contribute to a clearer picture as to the true age of the sediments in this core, in particular the basal dates, as luminescence dating is able to accurately date material that is temporally beyond the range of radiocarbon dating. Research in close proximity to the site under investigation in this thesis was undertaken by Coetzee, (1978) and Coetzee and Muller (1984). Evidence was presented from a number of boreholes taken approximately 2 km inland from the coast in the Noordhoek area. No dates are given for the age of the core sediments in these studies, but the sediments are described as Tertiary in age. The sediments were also divided into two separate units, a younger and an older

unit. The sediments from the older unit described in the (Coetzee and Muller, 1984) study are from a greater depth, and therefore are likely to be substantially older than the sediments studied in this thesis. The younger unit described in the (Coetzee and Muller, 1984) study is described as part of the Noordhoek member of the Bredasdorp formation, and is typified by the domination of fynbos families. The families described include the Proteaceae, Ericaceae, Compositae (Asteraceae), Chenopodiaceae, Graminae (Poaceae), Cyperaceae and Restionaceae (Coetzee and Muller, 1984). This pollen assemblage is in sharp contrast with the older unit which includes more tropical taxa, as well as a number of extinct pollen types.

It has been suggested that the establishment of a mediterranean type climate and subsequently the establishment of fynbos vegetation took place sometime in the early Pliocene (Goldblatt, 1997), and subsequently that it was unlikely that the sediments of the younger unit pre-date the early Pliocene. Coetzee and Muller (1984), however argue that the diversity of the Compositae (Asteraceae) in the younger unit is characteristic of sediments from the Upper Miocene, Pliocene, and even the Quaternary. The Noordhoek member of the Bredasdorp Formation runs from the surface to a depth of 21 metres below the surface, and it is presumed that as only the top 3 m of this younger unit are the subject of investigation in this thesis, that the sediments are of Quaternary age, and that the near-surface sediments are in fact Holocene in age. These presumptions could be further resolved by further dating of the sediments in question.

Zone 1 of the Lake Michelle core is dominated by families typical of Fynbos, such as the Proteaceae, Restionaceae, Ericaceae and a number of others. Of interest is the large proportion of Chenopodiaceae pollen in this zone, suggesting increased salinity. This

could perhaps be an indication of seasonal salinity episodes caused by a seasonal moisture gradient. This could also explain the presence of Cyperaceae pollen in large numbers in the zone. Of interest in this zone is the presence of *Podocarpus* pollen. The presence of this pollen could hint at moister, less seasonal rainfall conditions, but given the very low frequency of this pollen, tied to conditions inferred from other pollen present in this zone, it is difficult to test this hypothesis. The rapid decrease in pollen preservation toward the top of this zone would seem to suggest the onset of conditions not conducive to pollen preservation i.e. perhaps a reduction in available moisture.

Zone 2 is based on data from a single pollen data point, with sediments above and below this sample being devoid of pollen. This data point once again shows the presence of a number of typical fynbos taxa, but with less diversity than before. The spike in Chenopodiaceae could be indicative of marine encroachment leading to an increase in local salinity, as the sediments directly above this sample, and those of Zone 3 are devoid of pollen.

Zone 3 is presumed to be a zone typified by marine encroachment (see sea level curve later in chapter) This is based on evidence describing the sediments of this zone as grey in colour and containing marine shells and shell fragments (Akunji, 2005). In the context of this sedimentary sequence, Zone 3 is fairly long and may span a long time frame, a hypothesis which may be tested using alternative dating techniques to Radiocarbon dating.

Zone 4 is based on a single pollen data point, but it is from this depth that the radiocarbon date of 26,150±150 (31051±344 yrs B.P.) has been obtained. This sample once again shows presence of fynbos taxa, but also once again at lower diversity. The

presence of Chenopodiaceae at relatively high frequencies may be indicative of increased salinity, perhaps due to salt marsh conditions left by a retreating sea level. If the date attributed to this sample is accurate, it could be an indication that sea levels had begun to retreat, heading for the low sea levels of the LGM. The presence of conditions suitable for pollen preservation at this time may also support the argument for increased moisture availability toward the LGM that has been implied from other study sites (Parkington *et al.*, 2000; Scott and Woodborne, 2007b).

Zone 5 of the Lake Michelle core presents somewhat of a challenge in terms of interpretation. The majority of Zone 5 is devoid of pollen and organic material, and represents a hiatus in the palaeoenvironmental record. The exact reason for this hiatus is not known, but the following scenario seems plausible. It is possible that a marine transgression, followed by transgression, removed sediment from the area, and with it a large part of the environmental record. Following sea level retreat, terrestrial sediment accumulation recommenced, meaning that material of Holocene age would be directly above material dating back to before the LGM. This theory is supported by the establishment of a pollen assemblage near the top of Zone 5 which is very similar in structure and content to that of the present day environments at Lake Michelle. If this sea level were placed in the mid Holocene as is evidenced elsewhere in South Africa, including further up the West Coast at Verlorenvlei (Baxter and Meadows, 1999), this would imply that the material in the upper four units at Lake Michelle would be mid- to late Holocene in age. The relatively high frequency of Chenopodiaceae at the top of Unit 5 is consistent with higher salinity attributable to salt marsh conditions left by retreating

sea levels, or could also be attributed to warmer and drier conditions associated with the mid Holocene Altithermal as well as residual marine salt in the soils.

Zone 6 pollen spectra exhibit indications of the establishment of fynbos vegetation, typified by Proteaceae, Restionaceae and Ericaceae, as well as a number of others. The decrease in Chenopodiaceae linked with the appearance of Potomagetonaceae is an indication of increased availability of fresh water in the region. This is further supported by the increase in Cyperaceae in Zone 6.

Zone 7 of the Lake Michelle sequence appears to indicate a period of decreased moisture availability, with a decrease in Potomagetonaceae and Cyperaceae coupled with corresponding increases in the Chenopodiaceae, Poaceae and Asteraceae. This may be an indication of a move from an open freshwater system in the vicinity to a drier environment characterised by lowland fynbos. There are indications at the top of this zone of human influence in the region, including the first appearance of exotic pollen taxa and fluctuations in the prevalence of the indigenous taxa. These indications of human influence continue into Zone 8 of the sequence. Based on the palynological evidence, it can be presumed that the sediments from the top of Zone 7 and those of Zone 8 are very recent sediments, and in fact date back no more than a few hundred years at most. Evidence to support this argument can be found in the high proportion of exotic pollen taxa found in these two zones. Most exotic species have been introduced into the region within the last two hundred years. These exotic pollen types are represented by a number of families including Myrtaceae, signalling the introduction of both *Eucalyptus* and *Melaleuca* species into the region. Various *Acacia* species such as *Acacia cyclops, Acacia saligna* and *Acacia longifolia* have been introduced to the region for a number of

commercial and other reasons. The appearance of bi-saccate pollen grains in zone 8 has been attributed to *Pinus* with a number of commercial pine plantations located within a reasonable distance of the site for the presence of pollen from these trees not to be unusual or unexpected. It is possible that sedimentation rates in the upper four zones of the sedimentary sequence may have been higher than in the lower zones, meaning that the implied palaeoenvironmental changes in these upper sediments span much shorter time periods than those implied for the lower zones in the sequence.

6.2 Southwestern Australia

6.2.1 Wambellup Swamp

Wambellup Swamp has provided a pollen diagram which exhibits relatively low pollen diversity, when compared to the study site at Devil's Pool further to the west. Although the site is reasonably close to the Stirling Ranges, which is a recognised diversity hotspot (Myers, 2003), the site does not exhibit the same degree of topographical and hence climatic diversity found in the Stirling Ranges and this provide an explanation for a comparatively reduced biodiversity. Although there is no basal date for this sedimentary sequence, there are two dates from higher up in the sequence (calibrated ages provided in brackets). A date of 6936±46 B.P. (7791±54 yrs B.P.) was obtained at a depth of 1,95m while a date of 6709±44 B.P. (7573±40 yrs B.P.) was obtained at a depth of 1.05m. These dates place a large portion of this sedimentary sequence as Mid Holocene in age. These ages however, may be problematic, and would seem to indicate very rapid sedimentation rate over this period. This may in turn present problems in interpreting the temporal context of the rest of the sedimentary sequence. Further ages from both further up and down the sedimentary sequence could resolve the problem, giving a clearer picture as to the sedimentation rates and timing of sediment accumulation through the Holocene.

Evidence from Byenup Lagoon (Dodson and Lu, 2000) in southwestern Australia provides a record dating back to the early Holocene. The early Holocene vegetation at

Byenup Lagoon is described as a mix of *Eucalyptus* and *Casuarina* open forest with an understory of heath and some herbaceous species, including Chenopodiaceae. This vegetation pattern is also seen at Two Mile Lake, to the East of Wambellup swamp, a sample site with an age obtained from charcoal near the base of the core of 6,400 B.P. (Dodson *et al.*, in prep. pers.comm). The description of the pollen assemblage from Byenup Lagoon would seem to approximate the vegetation patterns and pollen assemblage observed in Zone 1 of the Wambellup Swamp sequence. This could possibly be taken as evidence that the lower sediments of the Wambellup Swamp sequence date back to the Early Holocene, or that there was little change in vegetation from the early Holocene moving into the mid Holocene at this site.

The presence of *Melaleuca* pollen in relatively high frequencies from the lowest zones of the Wambellup Swamp sequence, continuing through the sequence, may be taken as evidence for the presence of some type of fringing wetland woodland in the vicinity of this site dating back to the Early Holocene. As the details of sedimentation in the sequence remain somewhat unresolved, it is difficult to ascertain the temporal scale of any climatic or environmental changes inferred from the pollen data, but some trends may correspond with data from other study sites, perhaps giving a clue as to the historical placement of the sediments in the Wambellup Swamp sequence. The transition from Zone 1 into Zone 2 is coupled with the appearance of *Myriophyllum* and a small, but steady increase in *Melaleuca.* This may be an indication of an increase in available moisture with the development of a freshwater water body at the Wambellup swamp site. The reduction in representation of some of the herbaceous species may be due to the expansion of the wetland, and the increase in *Melaleuca* surrounding the wetland. This

may have displaced terrestrial, herbaceous species further away from the core site. *Myriophyllum* disappears toward the top of Zone 2, but reappears in Zone3, possibly indicating a cycle of expansion and contraction in the size of the water body. The radiocarbon ages suggest this expansion and contraction of the water body may have taken place over a matter of a few hundred years. If there was indeed increased runoff into the wetland during this time, it might explain the rapid sedimentation rates suggested by the radiocarbon dates. There is much debate as to the climatic conditions in the region around the mid-Holocene, with suggestions of both wetter (Churchill, 1968), drier (Itzstein-Davey, 2004) and no discernable change to climate (Newsome and Pickett, 1993). It is difficult to support or refute any of these arguments with the data from the Wambellup Swamp sequence due to the difficulties with the dating control however, it would appear that there are some fluctuations in the pollen record that may be indicative of changes in the local environmental conditions. Whether some of these changes can be attributed to climate change is a matter of debate. Zone 4 would seem to indicate a return to environmental conditions very similar to those described for the Early Holocene at Byenup Lagoon (Dodson and Lu, 2000) with *Eucalyptus* and *Casuarina* woodland with an under story of heath with some herbaceous species. Although *Myriophyllum* is not present in zone 4, there is a small increase in *Melaleuca* possibly signalling a change from an open water system to a wetland system, and thereby reducing the distance between surrounding vegetation and the core site. The slight increase in some of the herbaceous pollen taxa would seem to support this. The reduction in the *Melaleuca* toward the top of the zone coincides with an increase in a number of the herbaceous taxa, including the Chenopodiaceae. These factors may be further evidence of a reduction in

the wetland; with the stands of *Melaleuca* woodland which normally surround wetlands in the region today giving way to the *Eucalyptus* dominated open forest system with a heath understory containing some herbaceous elements. If this were the case, it would also explain the decrease in *Eucalyptus* pollen near the top of Zone 4, coinciding with a corresponding increase in *Casuarina*. This desiccation may have also led to an increase in salinity which would explain the increase in Chenopodiaceae. Further evidence from Byenup Lagoon suggests that from approximately 4700 B.P., *Eucalyptus* and *Corymbia* became the dominant tree species in that region (Dodson and Lu, 2000). If these conditions were to be extrapolated over the larger region, it would be useful in placing the base of Zone 5 in a temporal context.

Zone 5 shows the appearance of *Corymbia* in relatively high numbers. The arrival of *Corymbia* corresponds with a sharp decrease in *Casuarina* and an increase in *Melaleuca.* There is a little fluctuation in the frequency of *Eucalyptus* values, but there does not appear to be a significant change. It would appear that these changes in the pollen assemblage at this time might be attributed to an increase in available moisture, and an expansion of the wetland system once more. The argument for increased moisture availability appears to be supported by the decrease in Chenopodiaceae, indicating a reduction in salinity, and the appearance of Cyperaceae pollen, although the frequencies are relatively low. The expansion in the wetland would also explain the reduction in representation of some of the herbaceous types, particularly those taxa not pollinated by wind, as they were displaced further away from the core site.

Zone 6 presents an interpretive problem, with uncertainties surrounding sedimentation rates and the age of the upper most sediment in the zone. Dodson and Lu (2000) describe

a decrease in *Corymbia* in the late Holocene, with *Corymbia calophylla* re-establishing itself as a dominant species within the last few centuries. A similar pattern is clearly discernable in Zone 6 of the Wambellup Swamp sequence, suggesting that the top sediments from this core may indeed be very young in age. If these sediments are in fact very recent and only span the last century or two, it may explain some of the changes observed in Zone 6.

A decrease in *Eucalyptus* as well as a decrease in *Melaleuca* coupled with the increase in Chenopodiaceae may be an indication of post-colonial anthropogenic disturbance in the landscape. The removal of *Eucalyptus* and other vegetation to make way for agricultural land has resulted in an elevated water table and increased salinity in large areas of south-western Australia. This elevated salinity level would explain the increase in Chenopodiaceae, a saline tolerant family, and the decrease in *Melaleuca,* which is unable to survive in increasingly saline conditions. This increase in the Chenopodiaceae is also evident in the pollen diagram from Two Mile Lake (Dodson *et al*, in prep), a site further to the east near the Stirling Ranges. This salinity could be the result of seasonal drying out of the wetland, a phenomenon observed by the investigator on subsequent field visits to the Wambellup Swamp area, with an open water body in the wet winter season, being replaced by a muddy swamp system in the dry summer season. The raised water levels and seasonal flooding would explain the presence of Cyperaceae pollen in the sediments of Zone 6. The clearing of *Eucalyptus* would also explain the appearance of a number of taxa, such as various members of the Proteaceae, as well as an increase in frequency of a number of the herbaceous species as these prefer more open canopies and, signalling a

move towards a more mixed open woodland system as occurs today in the vicinity of Wambellup Swamp.

6.2.2 Devil's Pool

Two Radiocarbon dates (calibrated dates in brackets) have been obtained from the Devil's Pool stratigraphic sequence. One date from a depth of 200 cm below the surface has been dated at 2100±70 B.P. (2105±105 yrs B.P.), while another date from 460 cm below the surface has been dated at 3840±120 B.P. (4243±165 yrs B.P.). As yet there is no basal date from the bottom of this core at 895cm below the surface. Additional dates from further down the sedimentary sequence would help to place the entire sequence in a temporal context. If the sedimentation rate observed in the top half of the sequence were to hold true for the bottom half of the sequence, it would be expected that the basal sediments from this sequence would date back to the Early to Mid Holocene, but this remains speculative and requires further investigation.

What is clear from the pollen record obtained from these sediments is the relatively high diversity found at the site throughout the entire sequence. What is also obvious from the pollen diagram is the complexity and variation within each zone. How much of this complexity can be ascribed to climate changes is uncertain. The species complexity and diversity may be explained by the more complex soils and topography found in the coastal region when compared to the flatter inland regions (Hopper and Gioia, 2004). Hopper and Gioia, (2004) suggest that the flora is richer in the coastal kwongan regions, but also less diverse in the high rainfall forest regions. The area surrounding Devil's Pool

has an interesting mix of both elements and as such exhibits some of the diversity expected. There are however, broad general trends crossing a number of zones, which may give a better idea of longer term climatic and environmental changes. The environmental setting deduced from the pollen assemblage at the lowest reaches of the sedimentary sequence is one of a wetland in close proximity to *Eucalyptus* forest, accompanied by a number of other arboreal species, with an under story of heath and a number of herbaceous species. Although the *Eucalyptus* forest may have been denser at that time, compared to the present, this picture is not too dissimilar to the present day environments in the region.

Carbon isotope data from Devil's Pool represent δ C13 values for the entire core. These δ C13 values are all strongly negative, with an average value of -28.55‰. These values confirm the dominance of C3 vegetation at the site throughout the core, as does the pollen evidence. With a maximum value of -25.15‰ and a minimum of -31.74‰, there are clear indications that at no point in the sequence do the values shift toward the positive enough to suggest a significant presence of C4 vegetation. This would imply that at no time during the duration of the core, were conditions warm, or dry enough to favour C4 plant growth.

If the lower sediments of this core do indeed date back to the early Holocene, then evidence from Tunnel Cave in the general vicinity of Devil's Pool would adequately explain the high frequency of *Eucalyptus* pollen in the sediments of Zone 1. Evidence presented from Tunnel Cave attributes a post glacial increase in precipitation and available moisture to canopy encroachment by *Eucalyptus* (Dortch, 2004). The presence of *Melaleuca* as well as Cyperaceae pollen gives an indication of a wetland area, but not

necessarily of an open water body. The presence of a number of herbaceous species (particularly those taxa not pollinated by wind) in the pollen record of Zone 1 may be a reflection on the proximity of this vegetation to the core site, and is further support for the argument of the site being a wetland but not necessarily an open water body of substantial size. Zone 2 shows very little variation from Zone 1 with perhaps the only exception being the decline in *Banksia* pollen and an increase in a few of the herbaceous taxa such as *Haloragis*. Arboreal taxa remain dominant, in particular *Eucalyptus* giving a clear indication that moister climatic conditions continued from Zone 1 through into Zone 2. The first indication of a possible change in climate may be observed at the top end of Zone 2, continuing into Zone 3. In Zone 3 a relatively rapid decline in *Eucalyptus* is paired with an increase *Casuarina* and a small increase in *Banksia.* If the sedimentation rate of this core is constant, then the changes observed in Zone 3 would have taken place around the Mid Holocene, and could possibly support the argument for a drier phase during the Mid Holocene (Harrison and Dodson, 1993; Semeniuk, 1986). Further evidence for this is perhaps the presence of Euphorbiaceae pollen in the top of Zone 2 and into Zone 3. This family is known to contain a number of xerophytic species which would further indicate more arid conditions. Pollen evidence from Zone 4 shows a relatively stable *Eucalyptus* presence, but at much lower frequencies than before, while there is a decrease in both the *Casuarina* and *Banksia* pollen representation, this coupled to the light increase in Asteraceae, and the presence of both Chenopodiaceae and Euphorbiaceae, may be an indication of a further reduction in precipitation. The presence of *Myriophyllum* (an aquatic genus) may seem contradictory; however, with the rapid reduction in large canopy trees such as *Eucalyptus* in the region, there may have been an

increase in effective runoff leading to the formation of a fresh water body at the study site around this time. The expansion of this water body, may also explain the reduction in representation of some of the herbaceous and heath taxa, as they were displaced further from the sampling site. A further explanation could be an increase in seasonality of rainfall in the region, which would favour species able to withstand seasonal desiccation while disadvantaging those relying on a more even rainfall regime. Zone 6 is temporally a relatively large zone, and if the dates attributed to the sedimentary sequence are accurate, encompasses the transition from the Mid to Late Holocene. A number of changes in pollen taxa frequency are evident in Zone 6, which may give a clue as to changes in climatic conditions around this time. There may, however, be more than one explanation for the shifts in vegetation patterns observed. There are a number of small fluctuations in the frequency of *Eucalyptus* in Zone 6, however, levels generally remain constant, but at lower levels. While the level of representation of most of the arboreal taxa remain fairly constant, there is a discernable decrease in the representation of some of the herbaceous taxa, particularly the Chenopodiaceae, Haloragaceae and Asteraceae. What is obvious from Zone 6 is the gradually increased representation of the aquatic taxa such as Potamogetonaceae, *Myriophyllum* and the Cyperaceae. There is continued representation of most of the herbaceous taxa, Poaceae and Restionaceae. A possible explanation for this is an increase in moisture availability around this time, which would lead to the establishment of an open water body at the study site. This increase in available moisture would explain the reduction in taxa associated with more xeric conditions, such as the Euphorbiaceae, Chenopodiaceae and to a lesser extent Asteraceae. With the increase in moisture availability it would be expected that the representation of

arboreal species would increase accordingly. This is not the case, with representation of most of the arboreal species remaining constant.

A few explanations have been suggested for this. A number of fires in the region, both natural and possibly anthropogenic, have been blamed for keeping the arboreal species in check, and maintaining an open forest system in the region (Dortch, 2000; Dortch, 2004), Pickett and Newsome (1993) claim that the changes observed in the size and nature of the wetland systems in the region cannot be attributed to climate change, but are merely an expression of groundwater levels influenced by sea level fluctuations, particularly at sites in close proximity to the coast.

A third explanation for the lack of expansion of the arboreal species could be the increased influence of the westerly wind belt (Shulmeister *et al.*, (2004), which would lead to an increase in moisture availability, but also possibly an increase in the seasonality of rainfall, thereby promoting the establishment of taxa suited to seasonal rainfall gradients. What can be observed at the transition from Zone 6 into Zone 7 is an increase in both the *Eucalyptus* and the *Melaleuca* pollen representation. This tied to the rapid increase in both the Potomagetonaceae and *Myriophyllum* would appear to be strong evidence for a further increase in moisture availability in the region and a further expansion of the water body at the study site. Following this initial increase, Zone 7 is typified by an apparent decrease in *Eucalyptus* and *Melaleuca* representation as well as a very dramatic drop in *Myriophyllum.* These changes would seem to indicate a transition into a drier period than before and a change in the nature of the environments surrounding the study site. The pollen evidence would seem to suggest a much more open forest system with an under story of *Agonis, Casuarina* and a healthy representation of

herbaceous taxa. The evidence would also seem to suggest the reduction in size of the open water body, with the establishment of a swamp-like wetland system surrounded by substantial beds of Cyperaceae. The transition from Zone 7 and into Zone 8 is typified by a further decrease in *Myriophyllum,* but this is now coupled with a rapid decline in Potomagetonaceae. The further decline in *Melaleuca* tied in with the increase in Chenopodiaceae and the appearance of Euphorbiaceae may be an indication of a further deduction in moisture availability and a further reduction in the body of fresh water at the site, with expanding beds of Cyperaceae. The open forest system shows an increase in herbaceous species as well as an increase in Poaceae. Dortch (2000) attributes these changes in the forest under storey and particularly the increase in Poaceae to fires in the region, however, these changes may also be a climatic response by the vegetation.

It is difficult to resolve the factors contributing to changes in the pollen record observed in Zone 9. The further reduction in the aquatic species such as *Myriophyllum* and Potomagetonaceae coupled with the increase in Cyperaceae, Chenopodiaceae and Euphorbiaceae can be seen as further evidence for a reduction in moisture availability and further changes in the wetland system. Evidence to the contrary can be seen in the arboreal taxa, where a number of representatives of this group make a recovery and increase in representation in Zone 9. One plausible explanation for the changes observed in this zone is anthropogenic influence, in particular that brought about by post-colonial settlement in the region. The stronger representation of Poaceae in this zone may be due to the introduction of alien grass species into the region, while the increase in Asteraceae may be a clear indication of disturbance, as many members of the Asteraceae form part of pioneer communities following environmental disturbances. The increase in

Chenopodiaceae may not be significant, but may also be an indication of increased salinity, an issue associated with agricultural practices in Western Australia. Agriculture in the catchment area for Devil's Pool has undoubtedly influenced the flow regime in the region, having a direct effect on the nature of the wetland and the availability of moisture in the immediate vicinity. The recovery of many of the arboreal taxa may be attributed to the establishment of the Leeuwin – Naturaliste National Park (Dortch, 2000), in which the study site is located. The establishment of this park may have resulted in the re-establishment of natural flow regimes and vegetation patterns following on from a period of human disturbance. The overall picture for Devil's Pool is one of dense *Eucalyptus* forest becoming more open over time with the establishment of an under storey consisting of a number of arboreal, heathland and herbaceous taxa in response to various environmental factors including, more recently, post-colonial settlement of the landscape. The evidence also points to the changing characteristics of the wetland at the site, fluctuating between swampy marshlands dominated by Cyperaceae and an open water system with aquatic plants.

6.3 Comparison of Total Organic Carbon Content

The organic matter content of the material obtained from the various sample sites varies considerably from site to site. The site with consistently the highest values throughout the sequence is Wambellup Swamp, with a highest value of 85%. Although the lowest value of 9.5% near the base of the core is much reduced, there is relatively little variability in the values through the rest of the sequence, and much of the core is characterised by sediments with organic contents greater than 70%. This lack of variability would seem to

indicate consistent conditions for organic sediment accumulation throughout the sequence.

The most consistently low organic matter values are those of Lake Michelle in the Western Cape. With the exception of the surface samples, which exhibit high values, the average organic proportions lie between 1% and 11%, significantly lower than those found at Wambellup Swamp, and indicative of poor conditions for organic matter accumulation or pollen preservation.

The organic matter content for both Devil's Pool and the Bruno section exhibit high degrees of variability. Values for Devils Pool generally decrease with depth, proportions lying between 37.9% and 1.1%. The average values for Devils Pool are consistently higher than those of Lake Michelle.

The Upper 4 units of the Bruno section, along with units 6 and 7, exhibit negligible organic matter content, and it is only units 5, 8 and 9 that provided suitable data in this regard. There was variability in the organic matter values within these units, with Unit 5 producing values between 65.4% and 18.7% while units 8 and 9 produced values lying between 60.3% and 1.1%. In considering these data it is clear that the cores containing the sediments most consistently suited to pollen preservation are those from the two southwestern Australian sites at Wambellup Swamp and Devil's Pool.

6.4 Synthesis of Climate data

It is important to place the results obtained from the four study sites in question in context of regional climate changes in southwestern Australia, and the Western Cape, South Africa. Furthermore, it is also important to consider the possible role of major global or regional climatic events in producing the results obtained from the four study sites. The aim of Figure 6.1 is to compare climate reconstructions (in particular wet and dry phase inferences) from the four study sites with data from a number of relevant sites in the two study regions. The evidence is also placed in a temporal context and compared with the timing of important global climate events.

The basal age of the Bruno section would place the basal sedimentary units within the late Pleistocene period. The generally wetter climate signal would broadly concur with evidence from Pakhuis Pass (Scott and Woodborne, 2007b) which also indicates a wetter phase during the Pleistocene- Holocene transition, and continuing into the early Holocene. What may be of some significance is the alternate wet and dry phase in the basal units of the Bruno section. It is likely that the basal sediments for the Bruno section are too young for the observed changes to be attributed to the Antarctic Cold Reversal, a return to glacial conditions beginning at 14 500 B.P. and lasting 2000 years (Ahn, 2004; Petit *et al.*, 1999). Given the temporal placement of the basal units, this could be evidence

of the Younger Dryas event which took place in the late Pleistocene. Evidence of this rapid cooling event is generally more visible in the Northern Hemisphere, and is particularly evident from Greenland ice core data (Anklin *et al.*, 1997; Mayewski and White, 2002). Although some evidence suggests that the resultant effects of this event were too small to reflect in the southern African palaeoenvironmental record (Scott *et al.*, 1995), evidence from both marine (Cohen and Tyson, 1995) and terrestrial records (Abell and Plug, 2000) suggests, however, that this signal may well be present in a number of the records in the region. The palaeoecological evidence from the study sites was also scrutinised for evidence of the 8200 B.P. cooling event, an event similar to the Younger Dryas, but half the amplitude (von Grafenstein *et al.*, 1998). Even though there appears to be no definitive evidence for this event in the material from the Bruno section, it remains a point of interest. Implied climate data from the rest of the Bruno section, appears to broadly agree with the evidence presented by Chase and Meadows (2007) indicating drier conditions in the region during much of the Holocene period. There is however an anomaly in the Bruno record with a wet phase centred around the mid Holocene. This evidence concurs with a wetter phase suggested by charcoal evidence from Eland's Bay cave (Parkington *et al.*, 2000), but is in contrast to a synthesis of evidence suggesting that the mid Holocene period, also associated with the so-called mid Holocene Climatic Optimum or Altithermal, was the driest period of the Holocene (Chase and Meadows, 2007). This anomaly may be a result of localised conditions at the site rather than a reflection of regional climate variation.

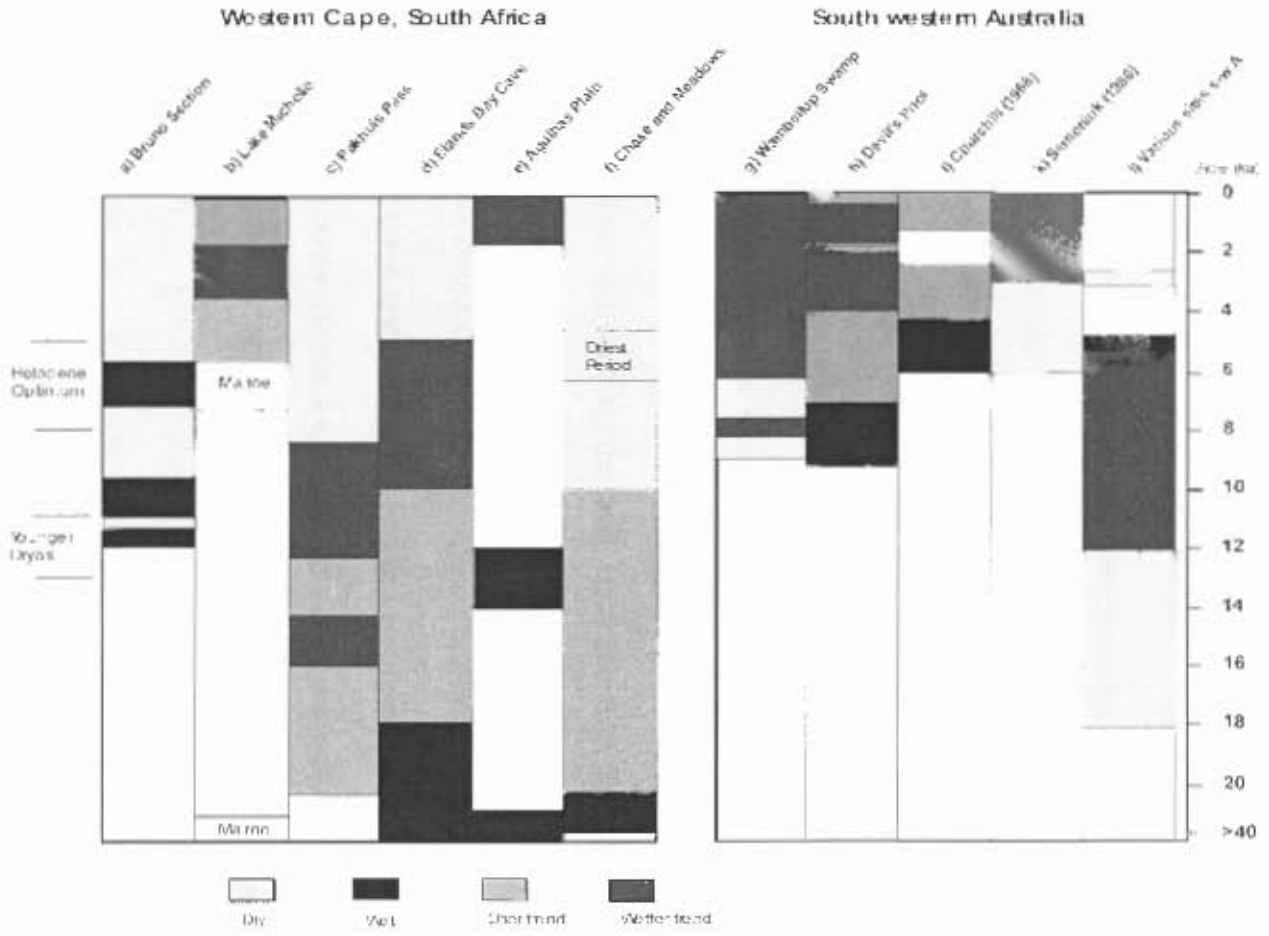


Fig 6.1 Summary of Climate data from the Western Cape and southwestern Australia. a) Bruno section (this thesis) b) Lake Michelle (this thesis) c)Pakhuis Pass (Scott and Woodbourne, 2007a,b) d)Elands Bay cave (Cowling *et.al.*,1999) e)Agulhas plain (Carr *et.al* ,2006) f) Chase and Meadows (2007) g) Wambellup swamp (this thesis) h) Devils' Pool (this thesis) i) Churchill (1968) j) Semeniuk (1986) k) Various sites sw Aus (Dodson and Harrison (1993), Newsome and Pickett (1997), Dodson and Lu (2001), Itzstein-Davey (2004).

Although evidence for the climatic effects of the Little Ice Age in Southern Africa has been presented at other sites, for example from speleothem data from Cold Air Cave (Holmgren *et al.*, 2003; Repinski *et al.*, 1999), there appears to be no definitive evidence for this event at either Lake Michelle or in the Bruno section. Due to the poor chronological control of the sediments of the Lake Michelle study site, it is difficult to place the sediments in context of regional climate variation. The basal date for the Lake Michelle core is beyond the range of the radiocarbon dating technique, meaning that no fixed temporal position can be assigned to the base. Lake Michelle is situated very close to contemporary mean sea level and it is clear from the core that marine transgressions have played a role at the study site, and it is conceivable that the main driving factor for vegetation change at this site is indeed fluctuation in sea level rather than climate change *per se*. Two marine transgressions are visible in the data, with the upper marine transgression being assigned to the mid Holocene high sea level stand (Compton, 2001)(see Figure 6.2). It is therefore presumed that the upper sediments of the Lake Michelle core accumulated after the subsidence of these mid Holocene high sea levels, thereby placing these sediments in the Mid to Late Holocene. Drier conditions at the site during the mid- to late Holocene would broadly concur with evidence presented at Elands Bay (Parkington *et al.*, 2000) and with a synthesis of material presented by Chase and Meadows (2007).

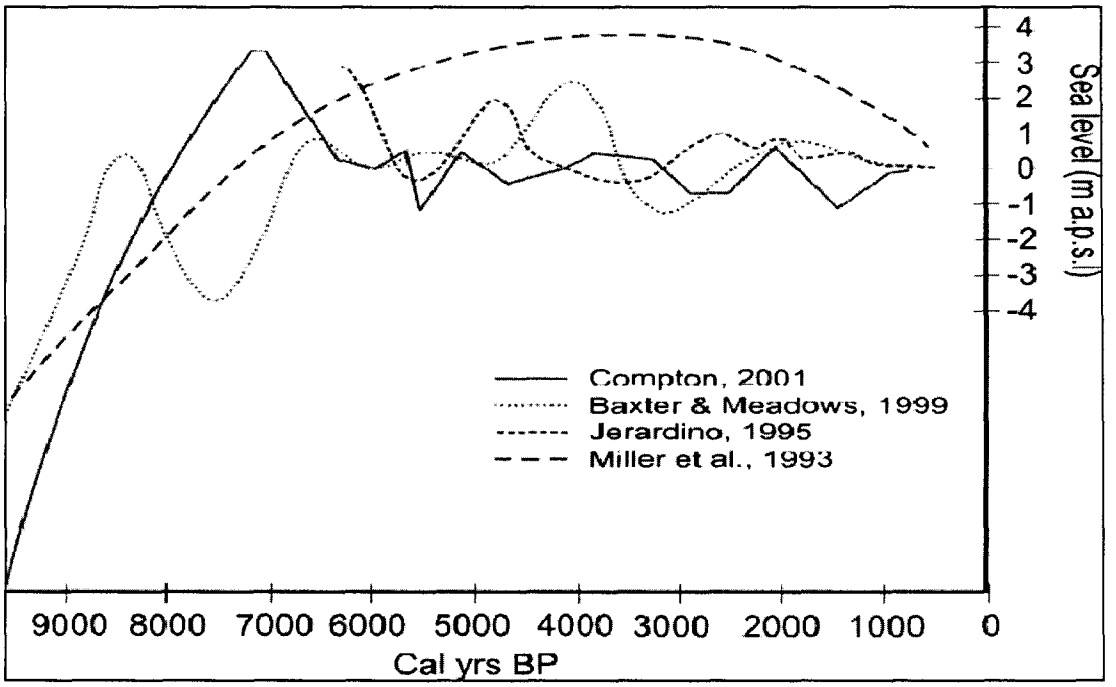


Fig 6.2 Holocene sea levels in the Western Cape.

The general trends that emerge from the data with regard to climate change in the Western Cape would be of a wetter Late Pleistocene (with possible evidence of a climatic excursion around the time of the Younger Dryas event) leading into a drying phase through the early Holocene. The mid- to late Holocene would appear to be a period of increased aridity, with the driest period centred around the mid Holocene. General trends emerging from the climate data generated at the Western Cape study sites would be of a wetter late Pleistocene, leading into a drying phase in the early Holocene period. The mid- to late Holocene would appear to be a period of increased aridity, with the driest period being centred around the mid-Holocene.

Although the key evolutionary events in the Cape flora predate the sediments in these sequences by a significant amount, the climate during the Late Quaternary could well

have played a significant role in maintaining or altering species diversity in the region. The maintenance of species diversity and level of species endemism in the region would have relied on the persistence of long term, stable refugia through the Quaternary (Linder, 2003). In the Western Cape, mountainous regions appear to contain the highest levels of species endemism, and indeed the highest numbers of palaeoendemics and have therefore been identified as refugia. These mountain ranges reduce the effect of rainfall seasonality and, therefore, in this region have the effect of locally reducing summer rainfall deficits. This has the effect of providing suitable habitat for plant taxa suited to moister environments (Verboom *et al.*, 2009). These mountain ranges would therefore seem to shield Mountain Fynbos vegetation from changes in rainfall seasonality. The same cannot be said for Lowland Fynbos, which would be more susceptible to climatic changes, especially fluctuations in moisture availability. It can therefore be seen that climatic variation over the Late Quaternary may have had a marked effect on biodiversity and the spatial distribution of vegetation in the region, particularly at lower altitudes.

The basal sediments from the Wambellup Swamp core remain undated, and an extrapolation of the existing date further up the core has led to a presumed age of approximately 8500 B.P. at the base. The climatic evidence from the lower units of the core show an alternating pattern of dry and wet phases leading to the mid Holocene. It would be tempting to place the lower dry phase in terms of the 8200 B.P. event discussed earlier, but without tighter chronological control on the lower sediments, this cannot be imputed with any certainty. A wetter trend at Wambellup Swamp begins in the mid Holocene, continuing through into the late Holocene. This wetter trend would seem to

make its appearance at an earlier stage when compared to data from a number of sites in the southwestern Australian region. Evidence from Byenup Lagoon (Dodson and Lu, 2000) indicates the onset of peat accumulation from around 4800 B.P., a pattern which they note is repeated at a number of other similar sites in the region. This onset of peat accumulation is taken as a clear indicator of the commencement of a wetter phase. The evidence from Wambellup Swamp fits broadly within this framework. A possible reason for this increase in moisture availability could be the strengthening of the southern hemisphere westerly wind belt, thereby increasing the effect of mid latitude cyclonic development associated with these westerly winds (Shulmeister *et al.*, 2004). There is a postulated poleward movement of the westerlies from 10 000 B.P. peaking at between 8000 B.P. and 4000 B.P., leading to a reduction in the effectiveness of the westerlies and a consequent reduction in moisture availability during that period. The trend is reversed in the later part of the Holocene leading to an increase in effective moisture availability over the past few thousand years. The implied climate reconstruction from Wambellup Swamp would appear to fit well within this framework.

The basal samples from the core taken at Devil's Pool remain as yet undated, but an extrapolation derived from the sedimentation rates and dates further up the core produces an age of approximately 9000 B.P. being assigned to the base of the core. This places the basal sediments of the core in the early Holocene. The implied climate data from the lower sections of the Devil's Pool core indicate a wet phase in the early Holocene. This wetter phase is in broad concurrence with a synthesis of climate data from a number of southwestern Australian sites which point to a wetter phase from the early Holocene

continuing through into the mid Holocene. There is evidence from Tunnel Cave in the Leeuwin- Naturaliste region of a post glacial increase in rainfall (Dortch, 2004). The mid Holocene at Devil's Pool would appear to reflect a somewhat drier phase roughly corresponding in timing with the mid Holocene altithermal. This more arid phase appears not to correspond to data from a number of sites in the region, except perhaps with that from the Swan coastal plain (Semeniuk, 1986), where a dry phase lasting from approximately 6000 B.P. and running into the Late Holocene is implied. The climate reconstruction for the period running from the mid- to late Holocene at Devils Pool would seem to indicate a wetter period with a few short lived dry phases in the Late Holocene. This generally wetter phase broadly concurs with the evidence from Wambellup Swamp, as well as the evidence from the Swan Coastal Plain (Semeniuk and Searle, 1986). The timing of the first short-lived, dry phase in the late Holocene appears to predate the Little Ice Age, and is centred around 2000 B.P., while the more recent implied dry phase may be a signal of human interaction with the environment rather than a climatic signal, with recorded human inhabitation of the region stretching back beyond the early Holocene (Turney, 2001).

The general trends that emerge from the climate reconstructions from the study sites in southwestern Australia appear to be poorly defined. The two sites present a picture of varying climate during the early to mid Holocene with a number of wet and dry phases. The picture for the late Holocene appears to be more coherent, with a generally wetter trend prevalent during this time. The evidence at the two sites does not stretch back far enough to provide any information about the Late Pleistocene or the Younger Dryas event, and the resolution does not provide any concrete evidence for the Little Ice Age

and of course the chronological resolution limitations prevail. The development of rich plant diversity in southwestern Australia also predates the Late Quaternary by a large margin but, as with the Western Cape, climate change during this time period would have played a significant role in maintaining or augmenting levels of biodiversity and establishing vegetation distribution patterns in the region. Following the rationale for mountainous regions in the Western Cape which are considered as refugia with high biodiversity and levels of species endemism, the very high levels of plant diversity found in areas of similar topography such as the Stirling Ranges in southwestern Australia may be similarly explained.

Summarising the inferred climate reconstructions for the two regions, it would appear that the late Pleistocene period was characterised by generally wetter conditions, with a possible indication of the Younger Dryas implied from the Bruno Section, although there appears to be much variability in the conditions associated with the early to mid Holocene. It can perhaps be said that the data from the two regions appear to broadly concur in the early Holocene, with wetter conditions implied in both regions, although this picture changes as one moves into the mid- to late Holocene. While both regions depend today on the southern Hemisphere Westerly Wind belt for winter precipitation, they both appear to have very different mid- to late Holocene histories. Generally arid conditions are implied for the Western Cape over this time period and, in particular during the mid Holocene altithermal. A generally wetter phase is implied for southwestern Australia over the same time period with no defined period of aridity assigned to the mid Holocene altithermal. The lack of chronological resolution at the

various study sites means that it is very difficult to assess evidence of short lived climate excursions such as the 8200 B.P. event as well as the Little Ice Age or Medieval Warm Phases. It is clear that the dynamic role of the southern Hemisphere Westerlies needs to be further investigated in relation to climate change in the two regions, as well as the effects of climate over the late Quaternary of climate variations on biodiversity and vegetation distribution. The marked effects of human interaction with the environment in these regions are discussed below.

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6.5 The role of human impact in the environment

It is attested that human impact in southern Hemisphere Mediterranean climate regions, both prehistoric, colonial and post colonial has had a marked impact on the resultant landscapes observed in these regions at present day. The key question that needs to be asked concerns the extent to which changes and signals of change in a number of pollen diagrams from the two regions, which have been attributed to environmental factors such as climate change, may in fact subtle indicators of human impact on the environment. Certain observable signals, such as the introduction of alien species into the fossil pollen record along with rapid changes in vegetation assemblages, can quite easily be distinguished and attributed to human impact, and in most instances to activities associated with colonial and post colonial settlement. More subtle changes such as those brought about by pre-colonial settlement are likely to be difficult to distinguish from subtle changes brought on by changes in climate and other environmental conditions. In a

Western Cape context there is an apparent contrast between the rapid, far reaching changes brought about by post-colonial settlement and the more subtle changes brought on by pre colonial, hunter–gatherer cultures and pastoralist cultures. The relative importance of these various impacts is, however, rather more difficult to ascertain; is it possible to link specific indicators from the fossil evidence with specific agents of impact? The proxy records generated from the study sites dealt with in this research are not all continuous, and do not all span the most recent parts of the Holocene. As such, proxy evidence from a number of additional sites in the Western Cape and southwestern Australia were also scrutinised and these data, derived from both pollen and charcoal proxies, have been discussed in conjunction with evidence generated in this research in order to identify certain trends in the evidence that would indicate specific disturbance mechanisms at specific times in history. The sites chosen are those that fall within the two regions, that present fossil pollen or charcoal evidence, or both, and which fall within a time period during which human impact would have been a factor contributing to environmental change in the respective regions.

6.5.1 The Western Cape

There is clear evidence for human impact at Verlorenvlei in the Western Cape, and in particular evidence of environmental impact as a result of colonial settlement in the region (Baxter and Meadows, 1994). Evidence from the pollen diagram points to rapid and drastic changes in the pollen assemblages beginning approximately in the mid 1700's continuing to the present day. Baxter and Meadows associate these changes with the

arrival of colonial agro-pastoralists circa 1700 AD. Notable changes in the pollen assemblage include the reduction in grass frequency coupled with an increase in the Asteraceae, a family associated with pioneer communities in disturbed environments which have been subjected to overgrazing, burning and clearing.

There is also a general decrease in diversity in the normally diverse fynbos pollen spectrum. The presence of *Acacia* pollen in the record is associated with the introduction of Australian species, in particular, *Acacia saligna* into the region. A further increase in karroid scrubland species at the expense of fynbos species, as well as the presence of Poaceae pollen associated with domestic cereal species, is further evidence of change associated with agricultural practices. The steady increase in *Typha* pollen through the more recent section of the pollen diagram has been attributed by Baxter (1996) to the local extinction of *Hippopotamus* from the wetland system, thereby removing the mechanism through which the open water system and channels were kept clear of vegetation. Evidence from the Klaarfontein Springs (Meadows and Baxter, 2001) which feed into the Verlorenvlei hints at pre-colonial impact by *Khoi khoi* pastoralists, with a steady decrease in Poaceae pollen representation dating from around 1900 B.P.. The evidence of colonial impact in the region is very similar to that from the Grootdrift cores extracted further seaward in the Verlorenvlei wetland. A study of a number of pollen sequences from the Cederberg in the Western Cape at Winterberg, Sneeuberg, Nuweveldberg and Driehoek (Sugden, 1989) all seem to indicate very little change in the pollen assemblage as a result of the arrival of *Khoi khoi* pastoralists dating to the time before colonial settlement. There appears to be very little fluctuation in the frequency of Poaceae and the composition of fynbos taxa also appears to remain constant throughout.

Changes that can be more confidently attributed to human influence all seem to be related to post-colonial settlement and associated with, for example, the introduction of exotic species such as *Pinus* and *Acacia* as well as the introduction of poplars to the region.

A study of a pollen diagram derived from Hyrax middens at Pakhuis Pass in the Cederberg (Scott and Woodborne, 2007a,b) provides no clear evidence of human impact in the region. Although there are fluctuations in the Poaceae pollen as well as the Asteraceae and karroid scrubland vegetation around 2000 years before present, these fluctuations do not appear to be any more dramatic than those predating this time period and therefore cannot be attributed directly to the influence of pastoralist tribesmen in the region before colonial settlement. This area is described by Scott and Woodbourne (2007a,b) as being generally dry with some variability dating back to approximately 4000 B.P. and, as such, may have been a relatively unattractive and inaccessible region for pastoralist herdsmen before colonial settlement. The pollen diagram also appears not to specifically identify exotic taxa which may have been introduced to the region by colonial settlers and could be used as evidence of human impact in the region. Pollen diagrams from Groenvlei (Martin, 1968) in the All Year Round rainfall zone were considered in order to identify evidence of human interaction with the environment in this region. Once again it would appear that the only obvious human induced changes evident in the pollen record are associated with the onset of colonial settlement in the region and that, if present, the changes induced by pre-colonial people are either not present or were too subtle to be reflected in the record of vegetation history. What is evident in the record is the onset of forestry activity in the region with the appearance of *Pinus* pollen in the sequence dating back a few hundred years. Along with this, there is

evidence of a decrease in frequencies of a number of pollen taxa including the Poaceae and Ericaceae. The decline in indigenous forest communities would seem to correspond with the period of maximum exploitation of the forest through timber extraction. Of interest is also the increase of Chenopodiaceae representation during this time of human settlement, possibly hinting at salinity issues as a result of increased fresh water consumption by human activities in the area. The increased fire frequency in the uppermost stratigraphic units of the pollen diagram can also be taken as an indication of increased human activity in the area.

What has become evident from pollen diagrams from various sites in the Western Cape is that the majority of the human impact deduced from these diagrams is as a result of colonial and post colonial settlement in these regions. Clear signals of this include rapid, large scale changes in the pollen assemblages associated with these regions, as well as the introduction of a number of alien species, many of which are associated with agricultural practices. Subtle changes associated with the pre-colonial pastoralists, such as the reduction in Poaceae at Klaarfontein springs, remain much more difficult to identify and at many sites, evidence of environmental impact by these cultures is almost impossible to discern.

6.5.2 Southwestern Australia

The history of colonial and post-colonial impacts on the environment in southwestern Australia occupies a similar time span to that in the Western Cape. The pre-colonial

history is, on the other hand, quite different as hunter-gatherer cultures were present in the landscape for a long period without the presence of traditional herdsmen or pastoralist cultures. As such, the indicators in the fossil pollen evidence of anticipated pre-colonial human impacts on the environment would be different to those found in the fossil pollen evidence for the Western Cape.

Human occupation in southwestern Australia has been dated back to 27 000 years B.P. (Dortch, 2004) and even as far back as 48 000 years B.P. (Turney, 2001). This evidence is based on a number of dates from cave floor deposits in a forested region of southwestern Australia. What this evidence suggests is that pre-colonial human occupation of the region by hunter-gatherer cultures predates the Holocene records from the region by quite some margin. This would present us with a further problem when analysing the pollen records for southwestern Australia in order to examine the effects of human impact on the environment as changes may not immediately be apparent in the pollen records in question. Changes associated with later settlement, for example colonial and post-colonial settlement, would be far more obvious. As the human occupation record pre-dates the Holocene pollen record, and indeed most of the pollen records from the region, it would make it extremely difficult to attribute changes in the pollen record to be a result of pre-colonial human activity, as the environment may have been in some sort of equilibrium with the activities of these hunter-gatherer cultures, making any signals associated with these activities appear as a "normal" environmental signal in the more recent pollen diagrams. It has been argued that one of the greatest impacts of pre-colonial hunter-gatherer cultures was to induce an increase in fire frequency in the region. This has been challenged and evidence has been presented claiming that fire has always been

an integral part of the environment in this region, and that fire frequencies have not in fact changed significantly over very long periods of time (Atahan *et al.*, 2004; Dodson *et al.*, 2005) It is expected, however, that the more rapid and geographically widespread changes brought about by colonial and post-colonial human activities (particularly those associated with agricultural practice and forestry) in the region would be evident in the pollen record of the region, and stand in contrast to the "normal" environmental signals in the pollen records. One of the problems encountered is the low number of high resolution pollen diagrams for sites in southwestern Australia, with just a handful of pollen diagrams providing the appropriate data for this investigation. Two sites in southwestern Australia, Boggy Lake and Loch McNess (Newsome and Pickett, 1993) are noteworthy in this context. Boggy Lake from the far southwest of Australia provided a pollen diagram spanning the last ca. 4500 years. There is a general trend in the pollen diagram, showing a decrease in terrestrial pollen input mirrored by an increase in aquatic pollen input. There are fluctuations throughout the sequence, but nothing that can unequivocally be attributed to human interaction with the environment. When the top sections of the pollen diagram, where one would expect to find signals indicating the influence of colonial and post-colonial settlement are analysed, a number of small changes can be noted. There is a decrease in Poaceae and Restionaceae pollen associated with an increase in a number of the arboreal and herbaceous vegetation types. Perhaps this is an indication of agricultural practices in the area, in particular the grazing of domestic livestock. The pollen diagram does not give any indication as to the introduction of alien invasive species, and as such it would appear that the changes in the pollen assemblage towards the top of the pollen diagram are relatively minor.

Evidence from Loch McNess (Newsome and Pickett, 1993), north of Perth in Western Australia spans a time period encompassing approximately the last 9000 years. The pollen diagram for Loch McNess also exhibits a number of fluctuations in the various plant taxa present at the site. There appears to be one significant event dated at 1370±200 years B.P. exhibiting a major decrease in terrestrial pollen types, mirrored by an increase in aquatic pollen types. There is however, no evidence that this can be linked to human influence in the region. The top sections of the pollen diagram exhibit some of the same trends as those observed for Boggy Lake with a decrease in Poaceae pollen as well as decreases in Cyperaceae and a few of the herbaceous pollen types. These changes, although not spectacular in their magnitude, may possibly be attributed to colonial and post-colonial human interaction with the environment. Dodson (2001) describes another pollen diagram produced by Pickett, E.J. at Lake Banganup, 20km south of Perth, as containing indicators of disturbance in the uppermost sections of the sequence corresponding to a significant change in charcoal frequencies. This evidence would seem to tie in well with colonial expansion in the region of Perth.

Evidence from Rottnest Island (Groves, 2001) off the coast of Perth in southwestern Australia presents evidence dating back to approximately 7500 years ago. There is little or no evidence of any pre-colonial disturbance, and it is a possibility that the island may not have been inhabited after its isolation from the mainland until historical times. This would seem to be supported by evidence from a charcoal curve from a recent study at Barker Swamp, also on Rottnest Island (Dodson pers.comm.) where it appears that charcoal inputs are low and that fires on the island were not anthropogenic in nature, There is evidence, however, of impacts associated with colonial settlement, with an

increase in sedimentation rates as well as an increase in arboreal pollen after the island was re-forested in more recent times. Evidence of post-colonial human impact at Byenup Lagoon (Dodson and Lu, 2000) is characterised by the appearance of alien species in the pollen assemblage, in this particular case the appearance of *Pinus* pollen. A more recent study from Two Mile Lake (Dodson *et al.*, in prep.) near the Stirling Ranges has produced a pollen record dating from the mid Holocene to the present. The site has also produced an accompanying charcoal frequency diagram. The pollen diagram shows much fluctuation in the representation of the major arboreal plant taxa in the region, with sharp reductions in the *Eucalyptus* representation matching a number of spikes in the charcoal record, indicating a reduction in response to fire. The *Eucalyptus* representation rebounds immediately after the fire episode. Whether or not these fire episodes are anthropogenic in origin or not is a matter of debate, but it would appear that there is some pre-colonial anthropogenic input into the nature of the environment in the region. If the top section of the pollen diagram from Two Mile Lake is studied, a number of changes can be seen which may well be an indication of colonial and post colonial impacts on the region. There is an increase in the Asteraceae and Chenopodiaceae pollen, possible hinting at disturbance as Asteraceae often make up members of pioneer communities, along with increased salinity, which is an increasingly common problem in southwestern Australia directly as a result of agricultural practices. There is also a small decrease in Poaceae, Restionaceae as well as a number of herbaceous pollen types hinting at a reduction in biodiversity in the region, possibly also evidence of anthropogenic disturbance.

6.6 Chapter Conclusions

What is apparent from an analysis of the relevant pollen evidence from southwestern Australia is that, as with the Western Cape of South Africa, human influence has definitely played a major role in shaping the environment in these regions as it is seen today. Evidence to support interaction in the landscape by precolonial cultures is not always as evident or easy to assess as the evidence of colonial and post-colonial land use within these study areas. The question remains as to the value of pollen analyses in determining solutions to these questions of human interaction, as the evidence is often subtle with the pollen diagrams not exhibiting fine enough resolution data to provide adequate answers or they are inadequately resolved chronologically. This is compounded by the paucity of fine resolution deposits which would allow for studies at a finer temporal scale. In both regions, perhaps data from a number of sources when synthesised would provide enough data to be able to piece together the human – environment interaction. Documentary evidence provides an important source of information, but self-evidently only dates back as far back as written records are available, while other scientific proxy data such as charcoal frequencies, sedimentation rates, geochemistry and archaeology provide useful additional information spanning much longer time frames.

Chapter 7: Conclusions

The research undertaken in this thesis was geared toward the fulfilment of a general research aim, which was:

To investigate the environmental history of high diversity heathland and related vegetation groups over the late Quaternary in southwestern Australia and the Western Cape of South Africa.

This was done in order to understand the mechanisms affecting and controlling extreme biodiversity in these two regions over the late Quaternary, a period of time associated with human impacts and unprecedented environmental change.

In order to achieve this, a number of objectives (also presented in the introduction) were identified and undertaken. These objectives have been met through the identification and sampling of four study sites, the Bruno Section and Lake Michelle in the Western Cape, South Africa and Wambellup Swamp and Devil's Pool in southwestern Australia. Pollen analysis and the provision of radiocarbon dates have provided data in order to be able to analyse environmental conditions, and place the samples in a temporal context. A number of specialised, but standard tools were employed to facilitate this research, for example the Tilia graphics package. Tilia has allowed for the graphical representation of the pollen data, and the CONISS function has allowed for the statistical manipulation of these data. Both of these have allowed the identification of trends within the data, allowing inferences to be made concerning vegetation response to variations in environmental

conditions. What has emerged from the data is environmental change and related shifts in vegetation community composition at each of the study sites at different rates and temporal scales both short and long term. This is exactly the type of data and resultant picture that is aimed for during the undertaking of this type of research. Although continuous records for the entire Holocene have proven difficult to produce, the evidence presented for the four study sites provides at least a clear picture of a number of time periods over the Holocene and glimpses of the late Pleistocene. The Devil's Pool site has provided the longest continuous environmental record of the four sites and, although the Bruno section has only provided data for certain time frames, these data when seen in conjunction with Scott's (2006, 2007) study from the Pakhuis Pass, provide an improved understanding of the late Pleistocene and Holocene conditions in the region. The Wambellup swamp site has provided insight into conditions in the mid to late Holocene in southwestern Australia, while the Lake Michelle site has provided some insight into pre LGM conditions in the Western Cape. The study sites also provide data which hints at human impacts in the two regions, and in particular post-colonial impacts spanning the last few hundred years. It is believed that the data generated by this research, presented together with appropriate and comparable data from previous research has achieved the general research aim, and has provided insight into the late Quaternary histories of the Western Cape and southwestern Australia.

7.1 Environmental conditions in southwestern Australia and the Western Cape

Data obtained from the study sites have been combined with previous research allowing for the comparison of particular time periods over the Holocene. This has also allowed for the comparison of prevailing environmental conditions in the two regions during similar time frames and enabled comment of the resultant vegetation patterns observed in the two regions. There seems to be contrasting environmental conditions experienced during the LGM in the Western Cape and southwestern Australia. Evidence for southwestern Australia indicates an arid period, characterised by periods of dune formation at a number of sites (Zheng *et al.,* 2003). The reason for this has been explained through the increased effect of high pressure systems over central Australia forcing reducing the effect of the westerly wind belt on southwestern Australia (Shulmeister *et al.,* 2004). Conversely, LGM conditions for the Western Cape, South Africa have been suggested as wetter conditions. This has been explained as a result of the northward expansion of Antarctic sea ice, forcing the effectively increasing precipitation (Chase and Meadows, 2007). It has been suggested though that there was a post glacial drying phase leading up to the early Holocene in the Western Cape. Although three of the study sites in this study do not have records extending back as far as the LGM, the Lake Michelle site in the Western Cape has radiocarbon dates placing at least part of this core at or before this time period. Pollen evidence from the Lake Michelle site at Noordhoek (this thesis) indicates that a number of families represented in the area at

present were represented at this stage, and that the prevalence of a number of these families in the region pre-dates the LGM.

The early Holocene in southwestern Australia appears to have been a time of increased moisture availability. The environment at Devil's Pool is characterised by a closed *Eucalyptus* forest, with a well developed under story. This data represents a forest much denser than what is found in the region today, a clear indication of increased moisture availability. Conditions in the Cederberg at the Bruno section indicate early Holocene conditions that are not as moist as those in southwestern Australia. A mix of scrub vegetation with some succulents would indicate a period of warmer and drier conditions than previously experienced in the region, however there is some variability with the presence of some arboreal taxa giving an indication of wetter periods. Trends in the environmental conditions during the mid Holocene period for both the Western Cape and southwestern Australia appear to be similar, with evidence of a drying out phase with warmer conditions in both regions. Pollen evidence from Devil's Pool indicates a reduction in *Eucalyptus* forest and the appearance of a number of more xeric taxa such as the Euphorbiaceae, leading to a more open *Eucalyptus* forest with an understory consisting of both heath and herbaceous taxa. This decrease in forest density and appearance of xeric taxa can be interpreted as a decrease in moisture availability, possibly on a seasonal basis. The conditions at the Bruno section also indicate a period of decrease moisture availability with an increase in more xeric taxa, such as the Aizoaceae as well as an increase in Asteraceae and a decrease in arboreal taxa. Vegetation around the Bruno site would have been dominated by scrub vegetation with some karroid elements. Arboreal elements may have been present, but restricted to areas of locally increased

moisture availability, as would wetland species such as the Cyperaceae. The transition into the late Holocene would appear to be characterised by an increase in moisture availability, and conditions cooler than those experienced in the mid Holocene. Pollen evidence from Wambellup Swamp indicates the appearance and increase in importance of *Corymbia* at the site, as well as an increase in representation of *Melaleuca* pollen. The inferred vegetation pattern describes a region characterised by open *Eucalypt* and *Corymbia* woodland with an under story of both heath and herbaceous species, and of a wetland area surrounded by increasing numbers of *Melaleuca.* This scenario would support the argument for conditions wetter than those experienced previously in the region. Although the environmental changes described here are general trends inferred from the data, there are many more temporally finer scale fluctuations in pollen representation of numerous taxa in the pollen diagrams. These temporally finer scale fluctuations suggest much variability in local conditions at each of the four study sites. It is not always possible to extrapolate these finer scale changes to produce a regional picture of environmental change.

7.2 Human impact in southwestern Australia and the Western Cape, South Africa

Evidence from a number of studies in southwestern Australia and the Western Cape has indicated the presence of humans in the landscape dating back many thousands of years. Evidence from palynological studies such as those from Klaarfontein Springs (Meadows and Baxter, 2001) show evidence of alteration of plant communities through *Khoi Khoi* pastoralism dating back 2000 years B.P. From the two study sites presented for the

Western Cape in this study, it has proven very difficult to identify any environmental changes that could be attributed to prehistoric human interaction. The influence of Aboriginal cultures on environmental conditions and vegetation patterns in southwestern Australia has long been debated. One school of thought attributes the maintenance of open forest systems and open heathlands to a fire regime introduced by Aboriginal settlement that predates the Holocene by some margin. Perhaps the maintenance of an open forest system at Wambellup Swamp could be attributed to Aboriginal burning; however, this may just as easily be explained as a response to climate variables. Similarly, the lack of expansion in *Eucalyptus* forests at Devil's Pool following more mesic conditions in the Late Holocene could be explained in terms of an increased fire frequency. This phenomenon however, could also just as easily be explained in terms of climate change, perhaps due to increased seasonality of rainfall in the region. It is evident therefore that no irrefutable evidence can be gleaned from the study sites with regards to prehistoric impacts and human-environment interactions. What are readily observed in both the Western Cape and southwestern Australia are the effects of colonial settlement and human-environment interactions spanning the last few centuries. Evidence from Lake Michelle clearly shows the introduction of alien taxa into the system in recent times, with the arrival of members of the *Acacia* genus as well as *Pinus* and Myrtaceae representatives. Evidence from southwestern Australia at Wambellup Swamp indicates human influence in the uppermost sediments of the core, with indications of increased salinity and alteration of the composition of plant communities in the region. This alteration in plant community composition is also evident at Devil's Pool, with further evidence of alteration of flow regimes in the local catchment area. There may also be

evidence of increased salinity at both Wambellup Swamp and Devil's Pool, an issue commonly associated with colonial agricultural practices in the region. A study of the uppermost sections of a number of pollen diagrams from both the Western Cape, South Africa and southwestern Australia have highlighted several issues with regards to identifying human influence in the environment from pollen records. In almost all of the records, it proved extremely difficult, or impossible to discern any change in the environment brought about through impact on the environment by pre-colonial, native cultures. The few changes that were discernable, involved subtle changes in grass pollen frequencies possible resulting from altered grazing practices. It proved very difficult to pick up on any changes in the fire regime brought about through the activities of these cultures. The most dramatic changes observed in these environments have been as a result of colonial and post-colonial influence in these regions. Large scale changes to plant communities as a result of agricultural practices, development of residential and industrial areas, changes in fire practices and land management and the introduction of alien species have all had far reaching consequences in terms of land degradation.

7.3 Biodiversity in southwestern Australia and the Western Cape, South Africa

Speciation in the Western Cape and southwestern Australian regions can be traced through various means as far back as the Cretaceous and have also been traced as recently as the Pliocene, all of which predates the material studied in this thesis (Hopper and Gioia, 2004; Linder *et al.*, 1992). It has been clearly established that the majority of plant families and levels of biodiversity present in the modern landscape in both the

southwestern Australia and the Western Cape have an ancient lineage, and were present in the landscape long before the start of the Holocene. Hopper and Gioia (2004) attribute this to an ancient flora found on very old, stable, weathered nutrient deficient landscapes, both influenced by oceanically moderated climates since the Jurassic. Evidence from the various study sites supports this argument, as the general levels of diversity implied throughout the cores is already present at the base of the core samples. Although there are fluctuations in the representation of a number of taxa throughout the Holocene in both regions, the general levels of diversity do not change drastically and there appears not to have been massive scale alterations in the composition of plant communities over this time period. The timing of Holocene climatic trends in the Western Cape and southwestern Australia may have differed at times, but both regions have been subject to climate changes over both long and short time frames, none of which would appear to have completely changed the composition of plant communities in either region. It would seem that the similarities in vegetation communities in the two regions can be explained in terms of convergence as discussed by (Ojeda *et al.*, 2001) where they state that subjected to similar regimes, both past and present, unrelated ecological communities will exhibit similar attributes. The vegetation communities in the Western Cape and southwestern Australia have a similar ancestry on the Gondwanan plate, with a number of plant families stemming from this common ancestry. This, combined with similar conditions in terms of relatively stable Pleistocene climates, relatively poor soils, similar fire regimes, Holocene climate variability and comparable levels of human impact may explain the vegetation patterns and communities in the two regions. Perhaps the maintenance of elevated levels of plant diversity during the Holocene period is a function

of the diversity in localised microclimatic and environmental conditions as a result of variation in water availability, variability in soils and nutrient availability, large altitudinal variability (particularly in the Western Cape), issues of aspect, distance from the coast combined with Holocene climate variability. This is further supported by Hopper and Gioia (2004), who attribute the higher species richness in the Western Cape to the more complex topography and soils as opposed to southwestern Australia. What is evident from the data generated in this research, is that the greatest alterations to the diversity of the flora in the Western Cape and southwestern Australia have taken place as a result of human interaction with the environment, as is evident from both the rapid decline and increase in certain species representation as well as the appearance of alien species in the natural flora. This has highlighted the fact that the single biggest threat to biodiversity in both regions stems from human impacts on the environment, particularly in the last few centuries, where evidence points to unprecedented rates of environmental change.

7.4 Recommendations

Although this study offers a glimpse into the prevailing environmental conditions in both the Western Cape and southwestern Australia over the Holocene period, there remains a critical paucity of data available to be able to draw conclusions about regional patterns of environmental variability. Further investigation is required, and perhaps the "holy grail" of palaeoenvironmental research may be uncovered; a continuous sequence spanning the

entire Holocene period, containing material providing suitable proxy data and high resolution temporal control. Further taxonomic research is also required to enable the identification of fossil pollen material to genus levels or below. This would provide more precise environmental data for palaeoenvironmental study sites. Although this study contributes to the pool of knowledge for these two biodiverse regions, there remains enormous scope for further research and investigation. Palynology, on the face of it would appear to be a blunt tool, poorly-suited to solving the questions posed by palaeoenvironmental research. Palynology would however, seem to have its place in this area of research provided the material under investigation is capable of good chronological resolution; it would definitely appear to work best when paired with one or more alternative proxy data source.

Improvements in dating techniques other than radiocarbon dating may prove extremely useful, where the lack of organic material and the prevalence of sandy material found in cores taken from sites in the Western Cape and southwestern Australia preclude the use of carbon dating. An issue that may be resolved by a more intensive chronological control is the phenomenon encountered by the author where a hiatus appears in the accumulation of sediments in a number of coastal sites in the Western Cape. This phenomenon is characterised by younger sediments placed directly on top of much older sediments. High resolution dating would bracket this hiatus giving insight as to the timing of this event. The sampling of a number of coastal wetland sites in the Western Cape would also provide information regarding the spatial extent of this phenomenon. The obvious recommendation is the sampling of more sites within theses regions in as many diverse environments as possible in order to combat the paucity of data available. This

will also add to the understanding of the complexity of evolution and maintenance of the diverse plant communities found in different environments within these regions. Alternative suitable proxy sources such as diatoms and microscopic charcoal may give further insight into palynological studies undertaken in the two regions, but in the author's opinion, improved, high resolution chronological control would go a long way toward giving a refined temporal scale to palaeoclimatic and palaeoenvironmental events and the results thereof.

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APPENDICES

POLLEN COUNTS AND OTHER DATA FOR BRUNO, LAKE MICHELLE, DEVIL'S POOL AND WAMBELLUP

Pollen counts for Bruno section, Unit 5

Depth	Myrtaceae	Podocarpus	Celastraceae	Proteaceae	Anacardiaceae	Olea	Ebenaceae
6.3	0	0	0	8	0	13	13
6.35	0	0	0	4	10	13	7
6.4	0	0	0	4	0	21	0
6.5	0	0	0	0	0	9	9
6.55	0	0	0	4	0	18	7
6.6	0	0	0	0	0	7	10

Pollen counts for Bruno section, Unit 5

Depth	Sapindaceae	Cyperaceae	Restionace	Poaceae	Chenopod/amai	Euphorbiacea
6.3	9	38	51	26	0	0
6.35	0	30	76	28	4	0
6.4	6	11	75	17	0	0
6.5	7	19	74	36	0	0
6.55	12	20	79	32	0	0
6.6	16	81	66	28	0	0

Pollen counts for Bruno section, Unit 5

Depth	Trilete spor	Amarylidac	Aizoaceae	Apiaceae	Campanulac	Ericaceae	Geraniacea
6.3	0	0	9	0	13	0	0
6.35	0	0	0	0	0	0	0
6.4	4	0	0	0	16	5	6
6.5	0	0	0	3	0	0	0
6.55	4	0	8	0	0	0	0
6.6	3	0	9	4	0	4	0

Pollen counts for Bruno section, Unit 5

Depth	Brassicace	Liliaceae	Loranthaceae	Labiatae	Malvaceae	Polygalaceae	Rubiaceae
6.3	0	0	0	0	0	0	21
6.35	0	0	0	0	0	0	14
6.4	0	0	0	0	0	0	11
6.5	0	0	0	0	0	0	29
6.55	0	0	0	0	0	0	0
6.6	0	0	0	0	0	0	13

Pollen counts for Bruno section, Unit 5

Depth	Rutaceae	Scrophular	Iridaceae	Asteraceae	Stoebe typ	Unidentified
6.3	17	6	0	55	7	14
6.35	16	0	0	81	0	17
6.4	13	0	0	84	14	13
6.5	19	0	0	57	23	15
6.55	14	0	0	71	0	18
6.6	19	0	0	24	0	16

Bruno Section, unit 5 Organic Matter Content

Depth	% organic
6.3	57.14
6.35	18.69
6.4	27.32
6.5	65.36
6.55	25
6.6	35.34

Pollen counts for Bruno section, units 8 and 9

Depth	Myrtaceae	Podocarpus	Celastraceae	Proteaceae	Anacardiaceae	Olea	Ebenaceae
9	0	0	0	9	13	0	0
9.05	0	0	0	0	0	0	0
9.1	0	0	0	0	7	8	23
9.15	0	0	0	0	0	0	5
9.2	0	0	4	0	0	0	10
9.25	0	1	12	4	0	0	6
9.3	0	0	0	9	0	0	12
9.35	0	0	0	0	0	14	0
9.4	0	0	0	4	0	0	4
9.45	0	0	0	4	0	0	15
9.5	0	0	0	3	0	12	0
9.55	0	0	0	4	0	12	0
9.6	0	0	0	0	7	13	3
9.65	0	0	0	0	7	12	0
9.7	0	0	3	7	0	19	3
9.75	0	0	0	0	0	13	10
9.8	0	0	3	4	4	13	7
9.85	0	0	0	3	0	8	11
9.9	0	0	0	0	0	0	9
9.95	3	0	0	0	0	7	4
10	0	0	0	6	0	15	8
10.1	0	0	0	0	0	12	11
10.2	0	0	0	5	0	16	4
10.3	0	0	0	0	0	11	6

Pollen counts for Bruno section, units 8 and 9

Depth	Sapindaceae	Cyperaceae	Restionaceae	Poaceae	Chenopod/amar	Euphorbiaceae
9	8	47	76	48	5	0
9.05	13	70	94	30	0	0
9.1	0	35	65	25	0	9
9.15	2	143	44	39	0	0
9.2	5	22	62	36	0	0
9.25	3	106	43	33	9	11
9.3	17	65	90	9	0	0
9.35	0	62	109	14	0	6
9.4	7	43	88	36	0	0
9.45	9	91	23	18	0	0
9.5	8	41	72	23	0	0
9.55	7	47	85	19	0	3
9.6	4	37	55	28	0	8
9.65	0	147	56	13	0	0
9.7	14	16	59	28	0	0
9.75	0	57	94	32	0	0
9.8	9	28	58	29	0	0
9.85	7	34	72	42	0	0
9.9	0	57	100	32	0	0
9.95	7	80	53	33	0	0
10	8	23	87	14	0	0
10.1	12	33	119	16	0	0
10.2	3	35	110	19	0	0
10.3	12	50	120	31	0	0

Pollen counts for Bruno section, units 8 and 9

Depth	Trilete spo	Amarylidac	Aizoaceae	Apiaceae	Campanulace	Ericaceae	Geraniacea
9	0	0	0	0	7	2	0
9.05	3	0	7	0	11	4	0
9.1	0	0	21	0	0	18	0
9.15	2	0	0	0	3	3	0
9.2	0	0	23	0	10	9	0
9.25	0	0	0	4	10	0	0
9.3	6	0	8	4	18	6	0
9.35	8	0	14	0	9	0	0
9.4	0	0	21	0	18	7	0
9.45	0	0	12	3	0	11	0
9.5	4	0	11	3	6	9	0
9.55	0	0	6	2	7	9	0
9.6	0	0	12	2	6	8	0
9.65	0	2	0	0	6	5	0
9.7	0	2	12	0	0	8	0
9.75	0	0	0	0	4	0	0
9.8	0	0	3	0	3	14	0
9.85	0	0	2	0	4	6	0
9.9	0	0	5	0	0	10	0
9.95	4	0	0	0	0	0	0
10	0	0	12	4	6	10	0
10.1	0	0	0	0	15	0	0
10.2	0	0	13	0	0	8	0
10.3	0	0	0	0	13	8	0

Pollen counts for Bruno section, units 8 and 9

Depth	Brassicace	Liliaceae	Loranthaceae	Labiatae	Malvaceae	Polygalaceae	Rubiaceae
9	10	0	0	0	0	0	16
9.05	0	0	0	0	0	0	3
9.1	0	0	0	3	0	0	6
9.15	0	0	0	0	0	0	0
9.2	0	0	0	0	0	0	18
9.25	0	0	1	0	0	8	8
9.3	0	0	0	0	0	0	9
9.35	0	0	0	0	0	0	17
9.4	0	0	0	0	0	0	22
9.45	0	0	0	0	0	0	10
9.5	0	0	0	0	0	0	7
9.55	0	0	0	0	0	0	18
9.6	0	0	0	0	0	0	16
9.65	0	0	0	0	0	0	2
9.7	0	0	0	0	0	7	11
9.75	0	0	0	0	0	0	8
9.8	0	2	0	0	0	0	8
9.85	0	0	0	0	0	0	14
9.9	0	0	0	0	2	0	14
9.95	0	0	0	0	2	0	11
10	0	0	0	0	0	0	15
10.1	0	0	0	0	2	0	11
10.2	0	0	0	0	0	0	11
10.3	0	0	0	2	0	11	11

Pollen counts for Bruno section, units 8 and 9

Depth	Rutaceae	Scrophular	Iridaceae	Asteraceae	Stoebe typ	Unidentified
9	6	0	3	27	18	5
9.05	7	0	0	32	16	6
9.1	6	0	0	28	33	13
9.15	11	0	0	26	6	16
9.2	9	3	0	34	24	16
9.25	0	0	0	18	16	7
9.3	0	0	0	26	7	14
9.35	0	0	0	5	26	16
9.4	19	0	0	7	0	17
9.45	7	0	0	37	0	14
9.5	8	0	0	63	17	13
9.55	6	0	0	46	12	17
9.6	7	4	0	51	27	12
9.65	0	0	0	7	0	16
9.7	0	0	0	73	14	11
9.75	6	0	2	46	13	15
9.8	21	0	0	60	18	16
9.85	0	0	0	5	23	17
9.9	17	4	0	10	28	12
9.95	10	0	0	56	12	18
10	20	0	0	43	14	15
10.1	21	0	0	13	6	15
10.2	22	0	2	40	0	12
10.3	0	1	8	0	16	10

Organic Matter content for Bruno Section

Depth	% Carbon
6.30	57.14
6.3	57.14
6.35	18.69
6.35	18.69
6.4	27.32
6.4	27.32
6.5	65.36
6.5	65.36
6.55	25
6.55	25
6.6	35.34
6.6	35.34
9	12.31
9.05	20
9.1	60.29
9.15	57.75
9.2	48.48
9.25	59.02
9.3	28.85
9.35	14.96
9.4	44.16
9.45	29.09
9.5	17.9
9.55	15.42
9.6	15
9.65	45.07
9.7	46.06
9.75	9.43
9.8	4.59
9.85	3.4
9.9	1.64
9.95	1.36
10	3.08
10.1	0.52
10.2	2.27
10.3	0.36

Pollen counts for Lake Michelle, Noordhoek

Depth	pinus-podocarpus	Myrtaceae	Acacia	Ebenaceae	Geraniaceae	Proteaceae	Ericaceae
0	5	9	5	3	8	5	4
0.1	7	0	5	0	8	5	6
0.2	0	0	0	0	7	5	0
0.3	0	0	0	0	7	0	0
0.4	0	0	0	0	9	4	6
0.5	0	0	0	0	6	0	8
0.6	0	0	0	0	4	23	6
0.7	0	0	0	0	0	0	0
0.8	0	0	0	0	0	0	0
0.9	0	0	0	0	0	0	0
1	0	0	0	0	0	0	7
1.1	0	0	0	0	0	0	0
1.2	0	0	0	0	0	0	0
1.3	0	0	0	0	0	0	0
1.4	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0
1.6	0	0	0	0	0	0	0
1.7	0	0	0	0	0	0	0
1.8	0	0	0	0	0	0	0
1.9	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0
2.2	0	0	0	0	0	4	11
2.3	0	0	0	0	0	0	0
2.4	0	0	0	0	12	7	9
2.5	1	0	0	0	12	8	8
2.6	0	0	0	0	8	1	9
2.7	0	0	0	0	11	9	7
2.8	0	0	0	0	12	7	8
2.9	0	0	0	0	12	8	8
3	0	0	0	0	0	0	0

Pollen counts for Lake Michelle, Noordhoek

Depth	Bruniaceae	Fabaceae	Myrica?	Apiaceae	Anacardiaceae	Ranunculac	Rubiaceae
0	5	0	0	0	0	0	0
0.1	11	0	0	0	0	0	0
0.2	17	0	0	0	0	0	0
0.3	11	0	0	0	0	0	0
0.4	14	0	0	0	0	0	0
0.5	17	3	0	0	0	0	0
0.6	11	0	4	2	0	0	0
0.7	0	0	0	0	0	0	0
0.8	0	0	0	0	0	0	0
0.9	0	0	0	0	0	0	0
1	17	3	0	3	0	0	0
1.1	0	0	0	0	0	0	0
1.2	0	0	0	0	0	0	0
1.3	0	0	0	0	0	0	0
1.4	0	0	0	0	0	0	0
1.5	0	0	0	0	0	0	0
1.6	0	0	0	0	0	0	0
1.7	0	0	0	0	0	0	0
1.8	0	0	0	0	0	0	0
1.9	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
2.1	0	0	0	0	0	0	0
2.2	8	8	6	0	0	0	0
2.3	0	0	0	0	0	0	0
2.4	0	0	0	8	0	5	13
2.5	0	0	0	8	0	0	0
2.6	0	3	0	7	0	0	0
2.7	0	8	0	8	0	0	3
2.8	0	12	0	4	0	0	7
2.9	11	6	0	0	0	0	0
3	0	0	0	0	0	0	0

Pollen counts for Lake Michelle, Noordhoek

Depth	Asteraceae	Sterculiacea	Polygalace	Malvaceae	Liliaceae	Chenopod/
0	51	0	0	0	3	50
0.1	50	0	4	0	0	34
0.2	71	0	0	0	3	29
0.3	49	4	0	0	0	0
0.4	57	0	0	0	3	19
0.5	72	0	0	0	2	9
0.6	42	0	0	0	3	57
0.7	0	0	0	0	0	0
0.8	0	0	0	0	0	0
0.9	0	0	0	0	0	0
1	83	0	0	0	4	52
1.1	0	0	0	0	0	0
1.2	0	0	0	0	0	0
1.3	0	0	0	0	0	0
1.4	0	0	0	0	0	0
1.5	0	0	0	0	0	0
1.6	0	0	0	0	0	0
1.7	0	0	0	0	0	0
1.8	0	0	0	0	0	0
1.9	0	0	0	0	0	0
2	0	0	0	0	0	0
2.1	0	0	0	0	0	0
2.2	43	0	0	0	4	27
2.3	0	0	0	0	0	0
2.4	46	0	0	0	7	28
2.5	84	0	0	0	4	22
2.6	37	0	0	0	2	47
2.7	21	0	0	0	0	57
2.8	40	0	0	0	0	29
2.9	31	0	0	0	0	29
3	0	0	0	0	0	0

Pollen counts for Lake Michelle, Noordhoek

Depth	Restionaceae	Poaceae	Cyperacea	Potamaget	Unidentified
0	10	79	50	9	7
0.1	23	60	75	0	12
0.2	23	32	86	6	16
0.3	20	47	119	24	12
0.4	14	42	92	32	13
0.5	17	60	72	19	15
0.6	15	35	81	0	17
0.7	0	0	0	0	0
0.8	0	0	0	0	0
0.9	0	0	0	0	0
1	11	49	55	0	16
1.1	0	0	0	0	0
1.2	0	0	0	0	0
1.3	0	0	0	0	0
1.4	0	0	0	0	0
1.5	0	0	0	0	0
1.6	0	0	0	0	0
1.7	0	0	0	0	0
1.8	0	0	0	0	0
1.9	0	0	0	0	0
2	0	0	0	0	0
2.1	0	0	0	0	0
2.2	74	0	97	0	18
2.3	0	0	0	0	0
2.4	58	0	82	0	13
2.5	47	0	77	0	18
2.6	58	0	102	0	16
2.7	49	0	109	0	18
2.8	79	0	85	0	17
2.9	98	0	76	0	21
3	0	0	0	0	0

Organic Matter Content for Lake Michelle, Noordhoek (from Akunji, 2004)

Depth	%C
0	41
10	9
20	2
30	1
40	1
50	1
60	1
70	1
80	1
90	1
100	1
110	1
120	2
130	2
140	4
150	5
160	5
170	7
180	9
190	7
200	9
210	8
220	7
230	9
240	9
250	9
260	8
270	9
280	10
290	9
300	11

Pollen counts for Devil's Pool

Depth	Eucalyptus	Bloodwood	Melaleuca	Agonis	Leptospermum	Darwinia	Casuarinaceae
0	5	0	7	13	3	0	8
0.2	4	0	3	3	2	0	5
0.4	9	2	4	4	2	0	4
0.6	6	1	4	3	2	0	6
0.8	8	1	8	0	2	2	6
1	3	0	5	3	0	3	6
1.2	18	2	7	2	1	0	2
1.4	21	4	12	3	3	0	4
1.6	29	3	17	1	2	0	5
1.8	18	4	9	2	9	1	4
2	24	4	10	3	15	5	5
2.2	7	1	4	2	2	0	4
2.4	8	0	2	1	1	0	9
2.6	13	0	2	2	5	0	4
2.8	6	1	3	3	5	1	7
3	15	2	4	2	3	0	2
3.2	10	1	3	2	8	0	2
3.4	19	2	2	4	3	1	3
3.6	21	2	2	5	4	1	4
3.8	17	1	1	4	8	2	3
4	21	3	6	7	8	0	6
4.2	9	1	4	4	4	0	16
4.4	21	5	2	5	1	0	4
4.6	27	4	3	9	4	0	9
4.8	36	3	6	14	6	5	8
5	30	7	11	7	8	5	26
5.2	30	4	6	9	4	2	27
5.4	39	6	11	9	4	2	19
5.6	39	4	11	4	2	2	13
5.8	61	6	6	10	5	1	8
6	55	6	8	10	5	4	3
6.2	70	3	8	10	7	1	1
6.4	71	4	11	9	7	1	1
6.6	55	3	7	11	5	1	0
6.8	68	2	10	11	9	1	0
7	58	1	8	10	13	3	1
7.2	58	4	10	8	11	1	1
7.4	50	7	18	5	5	0	5
7.6	58	15	12	6	6	0	1
7.8	63	5	8	12	12	0	7
8	61	9	13	12	9	1	2
8.2	60	4	12	11	6	1	3
8.4	55	8	12	11	12	1	3
8.6	59	5	8	15	9	0	4
8.8	62	3	11	15	11	1	3

Pollen counts for Devil's Pool

Depth	Acacia	Banksia	Hakea	Petrophile	Persoonia	Apiacaeae	Asteraceae
0	0	0	0	0	0	5	10
0.2	2	0	0	0	0	3	2
0.4	1	0	0	0	0	2	9
0.6	1	0	0	0	0	1	3
0.8	2	0	0	0	0	5	8
1	0	0	1	0	0	0	5
1.2	1	1	0	0	0	6	10
1.4	1	0	0	0	0	4	5
1.6	2	0	0	0	0	4	9
1.8	2	0	0	0	0	2	11
2	1	0	0	0	0	3	4
2.2	1	1	0	0	0	5	10
2.4	0	0	0	0	0	1	8
2.6	0	0	0	0	0	3	14
2.8	1	1	0	0	0	0	19
3	1	0	0	0	0	2	15
3.2	1	0	0	0	0	4	13
3.4	0	0	0	1	0	3	17
3.6	2	0	0	0	0	11	20
3.8	2	0	0	0	0	3	26
4	3	0	0	0	0	7	13
4.2	2	2	0	0	0	5	14
4.4	2	0	0	0	0	6	15
4.6	1	3	0	0	0	8	10
4.8	2	2	0	0	0	10	10
5	0	2	0	0	0	4	4
5.2	3	8	0	0	1	3	4
5.4	2	8	0	0	0	3	4
5.6	1	16	0	0	0	8	13
5.8	1	12	0	0	0	8	3
6	1	10	0	0	0	2	8
6.2	1	8	0	0	0	6	4
6.4	0	7	0	0	0	4	5
6.6	1	6	0	0	0	4	5
6.8	1	9	0	0	0	6	3
7	2	12	0	0	0	2	4
7.2	1	19	0	0	0	3	8
7.4	4	33	0	0	2	7	12
7.6	0	21	0	0	0	1	4
7.8	0	9	0	0	0	1	3
8	2	8	0	0	0	2	4
8.2	3	9	0	0	0	4	8
8.4	1	19	0	0	0	3	5
8.6	0	11	0	0	0	4	8
8.8	3	12	0	0	0	3	3

Pollen counts for Devil's Pool

Depth	Chenopodiac	Caryophyllace	Droceraceae	Epacridaceae	Euphorbiaceae	Goodeniac
0	5	0	0	0	5	3
0.2	3	0	0	0	3	3
0.4	2	0	0	0	0	3
0.6	0	0	0	0	0	0
0.8	2	0	0	0	1	0
1	2	0	1	0	0	0
1.2	2	0	0	0	0	0
1.4	4	0	0	0	0	1
1.6	4	0	0	1	0	0
1.8	4	0	0	0	1	0
2	6	0	0	1	0	0
2.2	6	0	0	0	0	0
2.4	4	0	0	1	0	1
2.6	8	0	1	2	0	1
2.8	7	0	1	1	1	1
3	4	0	0	0	0	1
3.2	3	0	0	0	1	6
3.4	6	0	0	0	0	1
3.6	5	0	0	0	5	1
3.8	14	0	0	0	4	2
4	3	0	0	0	4	1
4.2	5	0	0	0	4	3
4.4	6	0	0	0	3	3
4.6	3	0	0	0	3	7
4.8	8	0	0	0	5	9
5	5	0	0	1	3	4
5.2	9	0	0	0	5	3
5.4	4	0	0	0	3	6
5.6	9	0	0	1	3	5
5.8	1	0	0	1	8	0
6	2	0	0	0	5	1
6.2	2	0	0	0	2	0
6.4	3	0	0	0	7	4
6.6	5	0	0	1	6	0
6.8	1	0	0	0	2	1
7	3	0	0	0	0	4
7.2	4	0	0	0	0	1
7.4	2	0	0	0	1	1
7.6	3	0	0	0	1	1
7.8	3	0	0	0	1	2
8	2	0	0	1	1	0
8.2	0	0	0	0	1	1
8.4	3	1	0	0	1	0
8.6	0	0	0	0	0	2
8.8	0	0	0	0	0	2

Pollen counts for Devil's Pool

Depth	Hallogorac	Labiatae	Leucopogo	Liliaceae	Pappilionac	Pimelia	Plantago	
0	14	0	0	0	9	0	0	
0.2	15	0	0	3	4	0	0	
0.4	22	0	0	0	1	0	0	
0.6	14	0	0	0	0	0	0	
0.8	17	0	3	1	2	0	0	
1	15	0	6	1	2	0	0	
1.2	21	0	7	0	1	0	0	
1.4	19	1	3	0	2	0	4	
1.6	11	0	2	1	0	0	2	
1.8	15	0	6	1	0	0	2	
2	21	0	5	0	0	0	3	
2.2	34	0	4	0	0	0	2	
2.4	25	0	8	0	0	2	0	
2.6	16	0	10	0	0	2	0	
2.8	23	0	5	0	0	1	3	
3	20	0	5	0	0	0	0	
3.2	15	0	8	0	0	1	0	
3.4	20	1	17	0	0	0	0	
3.6	23	0	7	0	0	2	1	
3.8	38	0	12	0	0	5	1	
4	46	0	11	2	0	1	3	
4.2	28	0	11	3	0	5	2	
4.4	11	0	14	0	0	0	2	
4.6	20	1	13	2	0	1	0	
4.8	21	0	5	0	0	1	0	
5	22	0	11	1	0	4	0	
5.2	18	0	13	0	0	3	1	
5.4	33	0	9	0	0	4	1	
5.6	25	0	5	0	0	1	0	
5.8	29	0	3	0	0	1	0	
6	16	1	1	0	0	1	0	
6.2	38	0	4	2	0	1	0	
6.4	33	0	6	2	0	3	0	
6.6	31	0	5	4	0	1	0	
6.8	14	0	4	2	0	1	0	
7	23	0	3	2	0	0	0	
7.2	28	0	4	0	0	1	0	
7.4	4	0	6	1	0	0	0	
7.6	13	0	2	2	0	1	0	
7.8	19	0	5	2	0	2	1	
8	10	0	2	3	0	1	0	
8.2	18	0	4	3	0	1	0	
8.4	10	0	7	2	0	0	0	
8.6	26	0	4	4	0	2	0	
8.8	17	0	4	4	0	2	0	

Pollen counts for Devil's Pool

Depth	Poaceae	Polygonac	Restionaceae	Rhamnacea	Rubiaceae	Rutaceae
0	14	0	0	2	0	4
0.2	16	0	4	0	0	21
0.4	11	0	5	0	0	9
0.6	8	0	5	0	0	6
0.8	5	0	3	0	0	5
1	4	0	4	0	0	8
1.2	5	0	2	0	0	14
1.4	3	0	2	0	0	7
1.6	8	0	4	0	0	0
1.8	9	0	11	0	2	3
2	6	0	6	4	0	3
2.2	18	4	19	0	1	19
2.4	18	4	9	0	0	3
2.6	11	2	8	0	0	4
2.8	8	5	13	0	0	7
3	13	2	9	0	0	17
3.2	8	0	9	0	0	11
3.4	9	5	10	0	0	6
3.6	5	3	10	0	0	7
3.8	11	2	12	0	0	2
4	7	1	13	0	0	1
4.2	6	0	18	0	0	1
4.4	10	0	11	0	0	2
4.6	4	0	16	0	0	3
4.8	3	1	5	0	0	2
5	2	1	6	0	0	2
5.2	4	0	6	0	0	5
5.4	4	0	6	0	0	1
5.6	4	0	8	0	0	5
5.8	1	0	7	0	0	7
6	7	0	7	0	0	3
6.2	4	0	8	0	0	4
6.4	2	0	2	0	0	4
6.6	6	0	8	0	0	6
6.8	3	0	10	0	0	1
7	5	1	5	0	0	0
7.2	5	1	10	0	0	0
7.4	5	0	7	0	0	0
7.6	2	0	3	0	0	0
7.8	2	0	5	0	0	1
8	4	0	8	0	0	0
8.2	4	0	4	0	0	1
8.4	2	0	6	0	0	0
8.6	2	0	8	0	0	0
8.8	3	0	9	0	0	1

Pollen counts for Devil's Pool

Depth	Aff.Solanacea	Solanacea	Stackhousia	Sterculiaceae	Tremandacea	Xanthorac	Pteridium
0	0	0	0	0	2	0	5
0.2	0	0	0	0	3	0	0
0.4	0	0	0	0	2	4	2
0.6	0	0	0	0	1	3	2
0.8	0	0	0	0	0	5	1
1	0	0	0	0	0	3	0
1.2	0	0	0	0	1	3	0
1.4	0	0	0	0	0	4	1
1.6	2	0	0	0	6	4	0
1.8	3	0	0	0	8	4	1
2	7	0	0	0	19	2	1
2.2	0	0	0	0	4	2	1
2.4	0	0	0	0	6	2	4
2.6	0	0	0	0	6	2	0
2.8	0	0	0	0	9	0	4
3	2	0	0	0	5	2	1
3.2	1	0	0	0	5	0	5
3.4	0	0	0	0	5	2	3
3.6	0	0	0	0	6	1	3
3.8	1	0	0	0	3	2	3
4	3	0	0	2	9	7	4
4.2	1	0	0	0	5	0	2
4.4	0	0	0	0	11	2	4
4.6	6	1	0	5	9	3	3
4.8	0	0	0	8	9	1	1
5	0	0	0	5	8	2	2
5.2	4	0	0	5	7	0	3
5.4	2	0	0	3	9	0	2
5.6	0	0	0	4	2	2	2
5.8	0	0	0	0	14	0	2
6	0	0	0	0	17	4	2
6.2	0	3	0	1	9	2	0
6.4	0	1	0	0	8	2	0
6.6	2	0	0	0	10	5	0
6.8	2	0	0	0	19	3	1
7	1	0	0	1	21	1	2
7.2	0	0	1	0	12	1	1
7.4	2	0	0	0	7	3	1
7.6	2	2	0	0	33	1	2
7.8	6	0	0	0	18	1	2
8	4	0	0	0	23	1	0
8.2	2	0	0	0	18	2	5
8.4	1	0	0	0	14	4	2
8.6	0	0	0	0	15	3	4
8.8	0	0	0	0	20	2	0

Pollen counts for Devil's Pool

Depth	Cyperacea	Potamoget	Myripohylu	Typha	Unidentified
0	73	7	5	1	0
0.2	70	14	9	1	0
0.4	61	24	9	1	5
0.6	67	46	15	1	0
0.8	39	27	43	1	0
1	35	29	62	0	2
1.2	28	38	64	0	1
1.4	38	33	64	0	0
1.6	23	29	30	0	1
1.8	16	17	33	0	0
2	15	12	11	0	4
2.2	23	21	34	4	0
2.4	22	40	37	3	2
2.6	20	56	48	3	1
2.8	18	13	45	3	1
3	23	40	40	0	0
3.2	16	40	53	5	4
3.4	14	18	42	3	2
3.6	15	8	36	3	1
3.8	8	3	44	9	0
4	10	1	16	4	1
4.2	11	2	33	4	1
4.4	12	23	31	2	1
4.6	11	1	5	4	1
4.8	8	0	10	1	1
5	4	1	6	4	1
5.2	3	0	6	3	1
5.4	5	0	7	2	0
5.6	4	0	3	2	1
5.8	8	1	0	1	0
6	8	10	1	2	0
6.2	7	2	1	3	0
6.4	5	1	0	3	1
6.6	6	1	0	3	2
6.8	5	4	3	3	1
7	9	0	2	1	2
7.2	5	0	0	2	0
7.4	9	0	0	2	1
7.6	6	0	0	2	0
7.8	8	0	0	2	0
8	12	2	0	2	1
8.2	8	0	0	4	3
8.4	5	0	3	6	3
8.6	5	0	0	2	0
8.8	4	0	0	3	2

Isotope data and Organic Matter Content for Devil's Pool

Sample	Depth	%N	%C	Delta 15N	Delta13C
DP1	890	0.0376	1.106	4.56	-26.55
DP2	880	0.0378	1.099	3.66	-26.31
DP3	870	0.097	2.646	4.94	-25.39
DP4	860	0.1106	2.849	4.75	-25.57
DP5	850	0.0856	2.387	4.32	-26
DP6	840	0.1107	2.939	3.88	-25.72
DP7	830	0.3072	8.546	3.91	-28.24
DP8	820	0.0846	2.178	3.66	-26.15
DP9	810	0.0865	2.258	3.73	-26.08
DP10	800	0.4677	9.832	2.1	-29.3
DP11	790	0.7367	13.638	2.44	-28.78
DP12	780	0.5736	10.381	2.44	-28.16
DP13	770	0.7415	9.961	2.03	-27.54
DP14	760	0.5364	11.97	2.28	-28.62
DP15	750	0.5091	8.479	2.04	-28.85
DP16	740	0.7151	9	2	-28.29
DP17	730	0.834	11.369	0.87	-29.18
DP18	720	0.5549	7.414	2.68	-28.33
DP19	710	0.4721	6.062	2.98	-29.64
DP20	700	0.6781	7.905	3.68	-30.59
DP21	690	0.563	6.615	4.13	-30.23
DP22	680	0.3436	4.413	3.94	-29.5
DP23	670	0.4021	5.464	4.91	-29.45
DP24	660	0.4699	6.222	4.51	-29.72
DP25	650	0.2571	3.51	4.06	-29.86
DP26	640	0.5877	8.372	6.63	-29.18
DP27	630	0.4563	6.782	5.98	-29.63
DP28	620	0.4543	6.594	6.29	-29.73
DP29	610	0.4757	6.356	5.32	-28.98
DP30	600	0.4873	7.328	5.43	-29.15
DP31	590	0.5463	6.785	6.04	-29.87
DP32	580	0.5443	7.597	6.01	-28.57
DP33	570	0.3126	4.35	5.17	-29.74
DP34	560	0.5086	7.081	4.28	-29.72
DP35	550	0.4894	6.385	5.26	-30.45
DP36	540	0.3667	6.503	6.02	-25.15
DP37	530	0.7165	10.804	4.04	-29.96
DP38	520	0.9563	13.315	4.01	-31.38
DP39	510	0.9347	12.141	3.95	-31.74
DP40	500	0.7619	10.74	3.66	-30.38
DP41	490	0.7335	9.406	4.07	-30.31
DP42	480	0.8584	12.054	4.39	-30.6
DP43	470	0.9756	13.599	4.06	-30.45
DP44	460	0.8436	11.907	4.02	-29.46
DP45	450	0.4191	6.385	3.62	-28.27
DP46	440	0.9712	11.375	3.97	-30.59
DP47	430	1.1313	12.643	4.67	-31.23
DP48	420	1.1905	14.413	5.24	-28.81
DP49	410	1.2124	18.043	5.47	-28.41
DP50	400	1.3092	17.803	4.91	-29.5
DP51	390	1.287	17.22	4.74	-29.45
DP52	380	1.4218	18.468	4.58	-29.6
DP53	370	1.4139	19.323	4.99	-28.95
DP54	360	1.4165	19.016	3.74	-29.23
DP55	350	1.28	17.429	4.44	-29.52

Isotope data and Organic Matter Content for Devil's Pool

DP56	340	1.2665	17.1	4.34	-29.41
DP57	330	1.213	15.134	5.11	-30.36
DP58	320	1.3791	20.566	3.81	-28.62
DP59	310	1.1357	14.771	3.83	-29.3
DP60	300	1.367	19.328	4.18	-29.39
DP61	290	1.2518	16.461	3.85	-28.91
DP62	280	1.0923	14.236	4.54	-29.21
DP63	270	1.1246	14.128	6.05	-29.57
DP64	260	1.1468	16.819	4.28	-28.2
DP65	250	1.2835	17.551	4.37	-28.49
DP66	240	1.419	20.155	4.1	-27.87
DP67	230	1.3123	17.449	3.89	-28.97
DP68	220	1.4039	19.322	3.66	-27.79
DP69	210	1.2037	18.065	4.26	-27.28
DP70	200	1.2486	15.464	4.65	-28.3
DP71	190	1.0569	17.302	3.95	-27.24
DP72	180	1.4925	19.033	4.07	-28.02
DP73	170	1.0504	16.824	3.96	-27.65
DP74	160	1.11	18.728	3.11	-26.82
DP75	150	1.2462	22.392	3.59	-27.05
DP76	140	1.0051	16.631	3.3	-27.28
DP77	130	1.4493	24.921	2.56	-26.13
DP78	120	1.4047	24.458	2.71	-26.38
DP79	110	0.8929	15.443	2.13	-27.97
DP80	100	1.7563	28.67	3.02	-27.99
DP81	90	0.9101	20.391	1.87	-28.02
DP82	80	1.3434	35.72	2.66	-28.07
DP83	70	1.5553	33.408	1.88	-27.92
DP84	60	1.5722	35.462	0.68	-27.44
DP85	50	1.8985	37.856	1.6	-27.51
DP86	40	1.322	22.674	1.26	-27.75
DP87	30	2.0829	33.841	1.29	-27.5
DP88	20	2.6083	33.856	1.48	-28.01
DP89	10	1.2165	13.141	2.83	-27.34
DP90	0	1.873	24.347	4.15	-26.28

Pollen counts for Wambellup swamp

Depth	Eucalyptus	Eucalyptus2	Eucalyptus3	Casuarina	Acacia	Melaleuca	Epacridaceae	Chenopod/Amaranth	Asteraceae	Leocopogon	Poaceae
0	57	23	0	34	0	20	4	13	7	4	3
0.2	68	5	0	36	0	28	1	8	9	0	1
0.4	76	17	0	30	0	24	0	0	7	3	3
0.6	51	26	0	44	4	10	1	6	9	0	0
0.8	62	0	0	61	0	0	0	8	10	19	4
1	98	0	0	52	0	14	0	4	7	1	2
1.2	84	0	0	65	0	13	0	0	3	11	0
1.4	70	0	0	81	0	5	0	0	6	7	0
1.6	44	0	0	80	0	4	0	3	1	9	0
1.8	111	0	0	59	0	9	1	1	2	0	0
2	86	0	0	71	0	16	0	1	5	8	0
2.2	61	0	0	82	0	10	0	1	4	13	0
2.4	32	0	0	96	0	10	0	2	4	18	0
2.6	71	0	0	60	0	14	0	0	11	3	0

Pollen counts for Wambellup swamp

Depth	Restionacea	Proteaceae	Banksia	Haloragace	Hakea	Cyperaceae	Thymeliaceae	Myriophylu	Apiaceae	Liliaceae	Unidentified
0	30	0	0	0	0	0	0	0	0	0	5
0.2	31	1	1	7	1	2	0	0	0	0	0
0.4	18	0	0	20	0	0	2	0	0	0	0
0.6	38	0	0	5	0	3	0	0	0	0	0
0.8	35	0	1	0	0	0	0	0	0	0	0
1	18	0	0	0	0	0	0	0	0	0	4
1.2	24	0	0	0	0	0	0	0	0	0	0
1.4	31	0	0	0	0	0	0	0	0	0	0
1.6	50	0	0	0	1	0	0	8	0	0	0
1.8	6	0	0	0	0	0	3	0	0	0	0
2	8	0	0	3	0	0	2	0	0	0	0
2.2	18	0	0	0	0	0	0	10	1	0	0
2.4	17	0	0	14	0	0	2	3	0	2	0
2.6	25	0	0	13	0	0	3	0	0	0	0

Wambellup Swamp, Organic Matter Content through LOI

Depth	%organic
0	31.62
10	32.28
20	34.24
30	36.42
40	34.76
50	32.18
60	23.24
70	21.23
80	19.22
90	18
100	19.38
110	20.82
120	21.01
130	20.77
140	19.98
150	16.31
160	15.21
170	18.73
180	16.18
190	15.97
200	21.71
210	22.28
220	21.16
230	25.25
240	33.45
250	9.86
260	9.47